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1933-1934

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WORLD PETROLEUM CONGRESS, London, July 19th to 25th, 1933.

Arrangements are now well in hand for the World Petroleum Congress, which is being organised by the Institution of Petroleum Technologists.

The meetings of the Congress will be held at the Imperial College of Science and Technology, South Kensington, and a Programme giving particulars of the subjects to be discussed has been circulated.

Membership of the Congress is open to all persons interested in the Petroleum Industry, the Membership Fee being 10s.

Apart from the fact that only Members of the Congress will be permitted to attend the meetings and other functions connected with the Congress, they will have the privilege of purchasing preprints of the various papers, and the Report of the Proceedings to be published after the Congress, at a reduced rate.

Full details can be obtained from the Secretary, World Petroleum Congress, Aldine House, Bedford Street, London, W.C. 2.

DESIGNATION OF MEMBERSHIP.

Members wishing to indicate their membership of the Institution are reminded that the correct abbreviations as laid down in the By-Laws, Section III., Paragraph 9, are: Hon.M.Inst.P.T. for Honorary Member; M.Inst.P.T. for Member; A.M.Inst.P.T. for Associate Member; Stud.Inst.P.T. for Student; and Assoc.Inst.P.T. for Associate.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

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Editors are permitted to publish abstracts, providing that acknowledgment is made to The Institution of Petroleum Technologists.

Issue of Journal. The Journal is issued in twelve parts per volume, commencing in January of each year.

Members whose subscription is not in arrear receive the Journal free of cost, and additional copies are charged at the rate of 7s. 6d. per part, unless otherwise stated. A member whose subscription is not paid by March 31st of the year for which it is due is considered to be in arrear.

Changes of Address. Members are requested to notify any change of address to the Secretary.

Papers and Articles. Members are invited to submit papers to be read at the General Meetings of the Institution, and are specially asked to forward articles for consideration for publication in the Journal. Diagrams, illustrations, etc., should be suitable for direct photographic reproduction. Authors are informed that all papers, whether for reading or for publication, will be submitted to a referee nominated by the Publication Committee.

Authors of papers published in the Journal are entitled to receive 25 free reprints of their contribution. Further copies may be obtained on payment, and orders for these should be sent to the Secretary when the manuscript is forwarded to the Editor. The free reprints do not include any discussion which may be published with the paper, but authors may have such discussion included in their reprints on payment of the additional cost.

Galley proofs of the paper to be read at a General Meeting are available at the time of the meeting, but members desirous of receiving such galley proofs in advance should apply to the Secretary.

Binding of Journals. Members desiring to have their Journals bound in cases should send them, together with a remittance of 5s. 6d. per volume, to Messrs. Spcaight & Sons, Ltd., 98, Fetter Lane, London, E.C. 4. A charge of 7s. 6d. will be made for binding Vol. 10, 1924. Remittance in all cases must accompany the order.

Abstracts. Abstracts of the more important articles and patent specifications are published with each issue of the Journal, this supplement being paged independently of the transactions. Members and Journal Subscribers desiring to have the Abstracts printed on one side of the paper only can be supplied with these at a charge of 10s. per annum per copy, payable in advance.

Medals. The Redwood Medal is awarded, at the discretion of the Council, as and when desirable, but not more than once each year, to a petroleum technologist of outstanding eminence, irrespective of nationality or membership of the Institution.

A medal and a prize of five guineas is awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented the best paper during the session.

Benevolent Fund. The Benevolent Fund is intended to aid necessitous persons who are or have been members of the Institution, and their dependent relatives.

The Fund is raised by voluntary annual subscriptions, donations, and bequests, and all contributions should be sent to the Secretary of the Institution at Aldine House, Bedford Street, London, W.C. 2. The Fund is administered by the Council through the Benevolent Fund Committee, and all applications in connection therewith must be made on a special form which can be obtained from the Secretary of the Institution.

Appointments Register. A register of members requiring appointments is kept at the office of the Institution for the convenience of firms requiring the services of petroleum technologists, etc., it being understood that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library may be consulted between the hours of 10 a.m. and 5.30 p.m. daily. (Saturdays, 10 a.m. to 12 noon.)

Advertisements. Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from the Advertising Manager, at the offices of the Institution, Aldine House, Bedford Street, W.C. 2. (Telephone No. Temple Bar 1842.)

Prepaid small advertisements, such as situations vacant and wanted, patents for sale and miscellaneous, are accepted at a charge of 1s. per line of seven words (minimum 4s.). Box number 1s. extra. These should be sent to the Associate Editor not later than the 12th of the month in which it is desired they should appear.

LIST OF ADVERTISERS.

Members are desired when making enquiries or placing orders with advertisers to mention that they have seen their announcement in the Journal.

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Mr. R. Allan has returned home from Colombia.
Mr. C. T. Barber is home from Burma.
Mr. E. R. Cartwright has left Singapore and is in England.
Mr. A. P. Catherall has returned from Trinidad.
Dr. F. G. Clapp is in Persia.
Mr. H. C. H. Darley has left for Trinidad.
Mr. D. J. Hamilton has returned from Sarawak.
Mr. P. Kerr is home from Japan.
Mr. A. E. Page has returned to England from Trinidad.
Mr. S. T. Rogers is home from Ecuador.
Mr. K. B. Ross has left for Persia.
Mr. P. A. Stiff has returned to Persia.
Mr. G. E. Stott has left for Bermuda.
Mr. C. Thomas has returned from India.
Mr. G. F. Wallis is home from Mexico.
Mr. S. A. Ward has returned from Persia.
Dr. S. Zuber has left Poland, and is now in Italy.

The Secretary would be glad to learn of the whereabouts of the following members:—E. E. G. Agius, T. E. Beaumont, G. Bourkoff, A. F. Brown, J. M. Brown, A. E. C. Corbet, A. R. Crawford, E. H. Crush, W. H. Farrand, W. M. Gray, T. B. C. Harris, E. J. S. Hewitt, L. B. Holloway, P. N. Hulme, A. MacLean, J. McWilliams, R. E. Palmer, A. Rauch and L. N. White.

A.S.T.M. COMMITTEE D-2.

At the meeting of A.S.T.M. Committee D-2 on Petroleum Products and Lubricants, held on March 8th, in New York, in conjunction with the A.S.T.M. Spring Group Meetings of Committees, several actions affecting standards and tentative standards were approved. This committee sponsored the technical programme for the Regional Meeting, which consisted of a Symposium on Motor Lubricants, in which the Metropolitan Section of the Society of Automotive Engineers co-operated.

The following tentative methods of test were recommended for adoption as standard :—

Tentative Method of Test for Precipitation Number of Lubricating Oils (D 91—30 T).

Tentative Method of Test for Distillation of Crude Petroleum (D 285—30 T).

Tentative Method of Test for Dilution of Crankcase Oils (D 322—30 T).

Tentative Method of Test for Gravity of Petroleum and Petroleum Products by Means of the Hydrometer (D 287—32 T).

Tentative Methods of Sampling Petroleum and Petroleum Products (D 270—30 T).

Minor revisions have been proposed in the latter two specifications listed above. It is the intention of the committee to include these revisions when the test methods are advanced to standard.

Tentative revisions in the following standards are being proposed for advancement to standard :—

Methods of Test for Viscosity of Petroleum Products and Lubricants (D 88—30).

Method of Test for Flash and Fire Points by Means of Open Cup (D 92—24).

Method of Test for Cloud and Pour Points (D 97—30).

Action was taken at the meeting to recommend the revision of the Standard Methods of Test for Sulphur in Petroleum Oils heavier than Illuminating Oil. These revisions in general affect the accuracy of the test methods. Revisions in the Tentative Methods of Test for Penetration of Greases and Petrolatum were also approved.

Technical Committee C on Fuel Oils has been very active and progress was reported on the preparation of specifications for fuel oils. It is expected that proposed specifications will be available

for consideration at the June meeting of Committee D–2. In its work, Technical Committee C is giving consideration to the Government specifications for fuel oils.

Acting upon the recommendation of A.S.T.M. Committee D–2, the Method of Test for Knock Characteristics of Motor Fuels was approved for publication as a tentative standard by the Committee on Standards. This tentative method will be set in type immediately and as soon as available will be distributed for discussion, accompanied by a formal announcement.

AMERICAN CHEMICAL SOCIETY. EIGHTY-SIXTH GENERAL MEETING.

THE EIGHTY-SIXTH GENERAL MEETING of the American Chemical Society will be held at the Stevens Hotel, Chicago, Illinois, from September 11th to 15th, 1933.

The Technical Sessions will occupy six half days, and in addition the various divisions of the Society will hold ordinary meetings on subjects of current scientific interest.

At the same time, the World's Fair, which is formally called the "Century of Progress Exposition," will be in progress. Part of the Fair is devoted to what chemistry is and what it has done to create modern civilisation.

Extensive preparations are in hand for the entertainment of those attending the meeting, and the American Chemical Society have extended a cordial invitation to members of the Institution of Petroleum Technologists to be present.

SIXTEENTH SESSION OF THE INTERNATIONAL GEOLOGICAL CONGRESS.

The third circular for the sixteenth session of the International Geological Congress, which is to meet in Washington, U.S.A., from July 22nd to 29th, has been issued. It contains full information about meetings and about excursions, with costs. Before the Congress there are excursions to various parts of the Eastern United States, lasting from four to twelve days, and a transcontinental excursion eastward from San Francisco for those coming to the Congress from the West. For those arriving at New York too late to take part in these longer excursions there will be a number of short trips to nearby areas of geologic interest.

Alternate days during the sessions of the Congress will be given to excursions to areas around Washington.

After the sessions there will be two longer transcontinental excursions, each lasting 31 days, and two shorter excursions, one for the study of the glacial geology of the Central States, the other for the study of the pre-Cambrian area, including the iron and copper deposits, of the Lake Superior region.

In order to make these excursions generally available, it has been possible, through the generous assistance of the Geological Society of America, to offer the longer excursions at a considerable reduction below actual cost.

For special discussion at the scientific sessions in Washington the following topics are announced :—

Measurement of geologic time by any method.

Batholiths and related intrusives.

Zonal relations of metalliferous deposits.

Major divisions of the Palæozoic era.

Geomorphogenic processes in arid regions and their resulting forms and products.

Fossil man and contemporary faunas.

Orogenesis.

Geology of petroleum.

Copper resources of the world.

Membership in the Congress is open to any one interested.

For a copy of the third circular or other information address, W. C. Mendenhall, General Secretary, U.S. Geological Survey, Washington, D.C.

WORLD POWER CONFERENCE.

Arrangements are now well in hand for the Sectional Meeting of the World Power Conference to be held in Scandinavia from June 26th to July 8th, 1933. Full details are contained in Bulletin No. 4, copies of which can be obtained, together with all information, from the British National Committee of the World Power Conference, 63, Lincoln's Inn Fields, London, W.C. 2.

LIBRARY.

The following additions have been made to the Library since January **1st, 1933** :—

AMER. INST. MIN. MET. ENG. Competitive Relations of Coal and Petroleum in the United States. W. S. Hutchinson and A. J. Breitenstein.

—— Petroleum Production, 1932.

AMERICAN SOCIETY FOR TESTING MATERIALS. Index to Proceedings, Vols. 26–30, 1926–1930.

ARGENTINA. Estadiatica de Petroleo de la Republica Argentina durante el Ano, 1931.

BRITISH STANDARDS INSTITUTION. B.S.S. 479–1933. Coal Tar Naphthas.

—— B.S.S. 480–1933. Metal Sheathed Paper Insulated Plain Annealed Copper Conductors for Electricity Supply.

BROOKS, H. B., and A. W. SPINKS. A Multi-Range Potentiometer and Its Application to the Measurement of Small Temperature Differences. U.S. Bur. Stand. Res. Paper 506.

CROSS, R. Handbook of Petroleum, Asphalt and Natural Gas (1931 Edn.).

EVANS, P. Explanatory Notes to accompany a Table showing the Tertiary Succession in Assam. Trans. Min. Geol. Inst., India, 1932, XXVII., 155–260.

GEOLOGICAL SURVEY OF INDIA. Records, Vol. LXVI., 1932, Parts 2 and 3.

IRON AND STEEL INSTITUTE. Journal, Vol. CXXVI., Part II., 1932.

NEW ZEALAND OFFICIAL YEAR BOOK, 1933.

TRASK, P. D.—Origin and Environment of Source Sediments of Petroleum.

TWENHOFEL, W. H. Treatise on Sedimentation. 2nd Edn., 1932.

U.S. BUREAU OF FOREIGN AND DOMESTIC COMMERCE. Trade Inf. Bull. 805. Motor Fuels in Foreign Countries.

U.S. BUREAU OF MINES. Tech. Paper 535. Crater Wells, Richland Gas Field, Louisiana. H. B. Hill.

—— Tech. Paper 538. A Survey of High-Sulphur Crude Oils (Black Oils) Produced in Wyoming. H. M. Thorne and W. Murphy.

WHITE, J. D. and F. W. ROSE. Isolation of the three Xylenes from an Oklahoma Petroleum. U.S. Bureau of Standards Research Paper 501.

NOMINATIONS FOR MEMBERSHIP OF THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The following have been nominated for membership of the Institution of Petroleum Technologists and their Application Forms may be seen at the Offices of the Institution :—

As Members.	*Proposed by*	*Seconded by*
BACKLUND, Nils Olaf, Chemist, 77, Skaldenagen, Nockeby, Sweden	A. E. Dunstan	F. B. Thole
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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND FORTY-NINTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, London, W.C.2, on Tuesday, March 7, 1933, Mr. JAMES KEWLEY, M.A., F.C.S., M.I.Chem.E., President, occupying the Chair.

The following paper was presented by the author :—

The Migration of Oil and Natural Gas.

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INTRODUCTION.

IT is now over eighty years since Sterry Hunt[2] enunciated the main principles of the anticlinal theory of oil accumulation. Unlike his contemporary Andrews, who has been claimed by some to be the author of this theory, Hunt based his conception on the principle of flotation. Oil and gas, being lighter than water, floated above the latter in the porous rocks to the highest position obtainable. Normally, this meant that the oil and gas lay immediately below the impervious cap rocks, and an arched structure, such as an anticline, was ideal for oil and gas accumulation. Andrews' conception was that anticlines contained oil because they were full of fissures.[1]

Hunt's theory was for a long time refuted in the Pennsylvanian oilfields until Minshall and White[3] accepted and extended it to its modern form. This reluctance to believe an apparently obvious conception was largely due to the absence of definite structures in these older fields and to the dominance of rock texture rather than structure in governing accumulation. In other fields the importance of anticlinal folds was more readily proved, and the conception that oil and gas floated by buoyancy to the highest attainable position was readily accepted. Later it was pointed out, particularly by Munn,[6] that the oil rocks were not always water-saturated, and that in these circumstances the oil might well be found in the flanks of a structure or in the syncline, the position depending on the water table.

There were, however, a few protests against too ready an acceptance of these plausible views, mainly on the ground that oil separation in a sand above water was hindered by the capillary conditions. It was pointed out that the fundamental difference between the pay streaks and surrounding water sands was a textural one, the oil being found in the coarser beds. This led to a rival explanation of the phenomena of oil movement, by an appeal to the principle of capillary attraction as the complete explanation

of oil and gas segregation.[13] These two schools of thought were mutually antagonistic, and a literature has grown up containing both field evidence and laboratory experiments supporting the rival claims. At the same time there were others who saw in such phenomena as rock pressure, gas movement and water currents, other possible causes of oil migration which might supplement or replace the normal processes. Hence, as time progressed, ideas, instead of crystallising, have become more diffuse, and the whole question is now wrapped in confusion. There is no general agreement about the forces producing migration, about the extent of the movement involved, or the directions in which it is probable or improbable. There is not even a common visualisation of the nature of the problem, some writers giving all their attention to the movements within the reservoir rocks themselves, while others look only at the movements from the source rocks to the reservoir rocks. The majority think untidily in terms of both these separate movements, and fail to realise that they are fundamentally distinct.

There has been a considerable amount of experimental work applied to the solution of the problem. In physics or chemistry an experiment usually settles a problem, or at least makes one step forward towards solution, but experimental work often becomes misleading, particularly in the hands of untrained experimentalists, when it attempts to simulate natural phenomena. There are so many factors involved that it is difficult to strike a balance, and the deductions must be made with great caution. Some of the experimental work has been admirable, some has been utterly misapplied, and the deductions have been so contradictory that we find different individuals using the same evidence to support different conclusions. Thus, in the theory of capillarity, we have McCoy[39] suggesting a definite polar movement of the small oil and water globules under the influence of their adhesion or surface tension—he is not quite sure which—while Washburne,[13] who upholds the importance of the surface tension, claims that such polar movement is impossible and that the results are obtained in another way. Thirdly, a large number of writers claim, in opposition to both, that surface tension inhibits rather than it encourages movement. Each of these antagonistic views cannot be true, and one would have thought that the matter would have been settled long ago by simple experiment. The trouble is that solution has not been sought by simple experiment, but by experiments which have involved several contending factors and the results obtained have been difficult to analyse.

In the course of many years experimental work on the subject, the writer has attempted to build up a theory: firstly, by attacking

purely physical problems associated with the movement of oil, water and gas through capillaries; and afterwards by experiments in sand bodies, not so much to simulate conditions in nature, but to test components of these conditions. Such preliminary work must precede all large-scale work, to make sure that deductions are based on sound principles. Had such preliminary work been done much of the confusion on the subject would have been avoided. Thus, for instance, the experimental results obtained by Van Mills[27] in his beautiful studies of the movements within sand bodies are of profound importance, yet the writer is convinced that the deductions made from these experiments would have been considerably modified had the physics of the movements been better understood.

Where so much has been written it appears almost dangerous to add to the literature, and the writer has not stepped into the controversy until many years of investigation have convinced him that there are some new and illuminating facts which are worthy of record. The subject is so important that it must be cleared up; it strikes at fundamentals. No theory of oil origin is secure until we know the limits of oil migration. No intelligent study of oil accumulation can be made until we know the features which influence oil migration and its storage in bulk. There is no hope of obtaining the optimum extraction from our fields until we know more about the fluid movements that are set up within a reservoir as soon as we destroy its equilibrium by puncturing it with wells. In the present paper the writer will deal only with fundamental principles, leaving it to a future occasion for a discussion of the application of these principles to various geological and engineering problems in an oilpool.

The Processes of Migration.

Before attempting to discuss the causes of oil concentration, it will be as well to state what is involved in the term "migration." Most writers consider only the movements within the porous body, whereby gas, oil and water separate into three layers at different levels. Thereby they entirely forget the first and most important problem, the movement of oil and gas out of the source rocks, the argillaceous strata, into the porous reservoir rocks, such as sands and dolomites, in which it is discovered in the oilfields. This is the first process of migration and it is quite distinct in its problems from the movements within the reservoir rocks. The second process of migration is the movement of the fluids within the porous rocks which eventually lead to the segregation of the oil and gas in certain parts of these rocks. The general problems have been well set out by McCoy[42] in his discussion of

the subject, and though he inclines to the belief that the two problems have the same physical solution, he none the less emphasises that they are distinct. The writer proposes to emphasise this distinction by using the terms primary and secondary migration for the two processes. They may, and often do, grade the one into the other; there are some features in which they become identical, but in the main they are distinct, the physical conditions of the movement are different, and there is no justification for assuming that they are governed by the same causes.

This can be illustrated by a simple consideration. The source rocks are in the main argillaceous, and as rocks they are compact and highly impervious. They may allow a certain amount of movement through their mass along joint and bedding planes, but their porosity is low and the pores themselves are exceedingly small. No one could conceive that flotation would separate oil from water in such fine rocks, so that the simple and widely accepted explanation of all migration breaks down immediately we face the problem of the primary movement. On the other hand, the separation of oil, water and gas in a coarse sand or dolomite is a very different problem, and here flotation would have to be considered as a possible explanation.

One further point needs emphasis. It is impossible to separate the problem of primary migration from the question of oil origin. The questions, when, how and where the oil and gas originated are implied in the question of the source rocks and the history of what happens afterwards. Argillaceous sediments change considerably in the course of compaction. Their original water content may be from 80 to 90 per cent., and this water is pressed out at a rapidly diminishing rate as the sediments solidify. The movement of fluids through these rocks in the early stages of the process is easier than when they reach the compact stage. Does oil migration precede or succeed the main phase of compaction; in other words is oil formed sufficiently early in the sedimentary cycle to pass out of the fine rocks before compaction ceases?

Primary Migration.

In the first phase of oil and gas movement the source rocks lose a part of their oil and gas content, which travels to the adjoining porous rocks. Generally argillaceous beds predominate in the geological sequence of oilfields, and though all these may not be source rocks, indeed many are almost certainly not so, yet the thickness and lateral extent—*i.e.*, the total bulk of the source rocks—is very much greater than the volume of the oil and gas pools. There is no reason, therefore, to suppose that the original

oil concentration in the source rocks is necessarily high. Some of the oil is retained in the source rocks, some of the oil may become dispersed and lost, a portion is suitably caught in the reservoir from which it can be extracted commercially. But even allowing for all these factors, there is no reason to demand a high original oil content in the source rocks. This conclusion is supported by other evidence. It is now realised that oil is much more abundant and widespread than was originally supposed. Hence oil source rocks must be normal to particular conditions of sedimenation and must be fairly widespread under such conditions. Exceedingly rich organic deposits are usually local. It is therefore likely that the common source deposits of oilfields contain quite moderate quantities of organic matter, and that the oil from this is segregated later on. The writer does not suggest that rich organic deposits do not occur sometimes, but merely that special and peculiarly rich accumulations of organic matter are unnecessary as the first step in the production of an oilpool.

Our primary conception is therefore a fine-grained source rock containing some organic matter which is later turned into oil and gas. For reasons which will be stated later, the writer believes that this change takes place in the early stages of compaction. The questions which have to be answered are: how does the oil reach the reservoir rocks? and why is it retained in them and its concentration increased?

Flotation.—The principle of gravity separation or flotation in fine rocks is not applicable. Whether the clays are uncompacted, or compacted, the capillaries within them are too fine for gravitational sorting to take place. It has, however, been claimed by some that oil separation can be largely helped by rising gas bubbles to which the oil clings, and which therefore cause separation when it would otherwise be impossible. This is undoubtedly true of moving bubbles in a sand, but gas bubbles entangled in the fine capillaries of silts and clays set up a considerable back pressure which tends to inhibit fluid movement, and therefore hinder rather than help migration.

Capillarity.—It has been suggested in the face of the difficulty to apply the flotation theory that the whole question of oil separation is dependent on capillarity. Probably this conception was first suggested by the undoubted fact that often in a producing rock a "pay" streak is merely a sand which is coarser than the surrounding rock. This is particularly true of the thicker sand bodies in the Appalachian fields, where the oil sands were often coarse gritty lenses in a fine sand rock. The surface tension of an air-water film is about 72 dynes per square centimetre;

a corresponding surface tension of an air-oil film varies with the nature of the crude oil, but is approximately about 20 to 25 dynes per sq. cm. It is therefore claimed by Washburne and McCoy that, because the surface tension of the water is nearly three times that of the crude oil, the tendency will be for the oil to be driven to the coarser sands, whilst the water moves to the finer rocks where the capillaries are smaller. The theory is plausible, but becomes vague and unsatisfactory on close examination. From a purely physical standpoint, it is untenable, but that has not hindered geologists from giving it their blessing, and it is therefore necessary to consider the theory more closely in view of the wide support it has received.

Firstly, it may be pointed out that though both McCoy and Washburne suggest this as the primary cause of oil movement into the coarser rocks, they differ completely in their view of the modus operandi. McCoy, following Cook, explains the movement as due to the superior adhesive power of the water for shale or silica, whereby the water slowly creeps along the capillaries, impelling drops of oil in the reverse direction.[42] This creep is towards the fine capillaries, and the displaced oil has to move in the reverse direction. As McCoy admits, his theory is based largely on adhesion, and he is very vague in his endeavour to explain how the process can act within a body of sand or clay and not merely on the boundaries. Washburne, on the other hand, denies the possibility of directional movement of the small oil and water drops in the capillaries. He attempts a more general explanation behind the generalisation, that there will be a tendency for the reduction of surface energy, which in time will lead to the formation of large and ever larger drops. These will accumulate in size until ultimately they are large enough to be affected by gravitational flotation, when the fluids will be able to overcome surface tension and the oil will float upwards. Whether this is a theory to explain segregation of oil in sands only, or whether he would apply it also to the source rocks, is not clear, but in any case it is obvious that the two explanations of migration by capillarity are in direct conflict. It is admitted by Washburne that in any case capillary pressure cannot be the cause of the pressure in an oilfield, for capillary pressure is negative—*i.e.*, a pressure away from the reservoir rock towards the fine rock, a sort of super vacuum which is difficult to visualise and still more to explain away. The acknowledgment is a serious weakening of the case for capillarity, for it seems probable that whatever force produced the migration was at least partly responsible for the pressure conditions afterwards.

Now the whole case built up by McCoy and Cook is based on

experiments which do not bear critical examination.[24], [25] Their description of the experiments lacks all the precise details which should form the essence of careful work. There is sufficient evidence that they failed to arrange that their original pressure system should be a balanced one, nor did they appear to realise the necessity for such a balance. In one experiment they took two glass tubes, one filled with a coarse, water-saturated sand, and the other with a fine, oil-saturated sand, connected by a capillary, and stated that over a period of three or more months the water gradually penetrated the oil sand and displaced the oil. The experiment proves little or nothing. It is obvious from the sketch, the lack of statement of suitable precautions, and the form of the conclusions, that the authors did not realise what forces were at work, nor did they appreciate that there would be obvious inequilibrium of hydrostatic pressure on either side of such a system, with the chances heavily weighted in favour of the water having excess pressure and driving over into the oil sand. The processes which they discovered in the central capillary would be normal, provided this capillary was first wet with water, but they do not even mention this important detail.

In another experiment described by McCoy with coarse and fine sands overlain by oil-saturated clay, he fails to give data on the most important point in his experiment. Was his oil-saturated clay completely compacted or was it merely a clay mixed with oil from which the surplus oil had been removed? In the latter case the gradual compaction of the clay would influence the expression of the oil, and the movement of the oil to the coarse rocks would be in accordance with the processes of segregation, which will be outlined later. A third experiment in which a water movement failed to dislodge oil contained in a coarse sand patch does not in any way prove that capillarity is a force producing migration. It is a further illustration of the principles which the writer maintains, and will explain later, that oil is trapped at a coarse fine interface in a water-wet sand.

A simple experiment, which avoids such obvious criticisms of a lack of hydrostatic balance, can be arranged as follows :—A single converging capillary is filled with oil and water in separate drops. This can be repeated in separate capillaries, some originally water-wet and others oil-wet. The tubes are then immersed horizontally in water, and the form and position of the bubbles can be watched. Such experiments have been carried out by the writer, and showed that no movement takes place. The tubes were kept over a long period, and show that the positions of the oil-water zones remain unchanged. It is difficult

to see on general physical reasoning how any movement could take place.

McCoy's explanation of movement by capillarity or adhesion is based on experiments which are erroneously interpreted. It is contradicted by properly arranged experiments, and is in conflict with well-accepted physical principles. We may therefore discard this explanation as worthless.

The explanation of capillarity by Washburne[13] is primarily based on the assumption that the surface energy of the systems will tend to diminish by the fusion of neighbouring oil drops, until the whole drop system has become large enough to float upwards against the action of surface tension, which had previously resisted movement. How such fusion can take place in a static system with the oil drops separated by water and held in capillaries he does not explain. Like many generalisations, it is not so easy to combat as a specific statement; none the less, it cannot be supported on physical grounds. It is true that in emulsions there is a tendency for large-drop formation, but even here contact of drops is necessary, and the position in a sand or clay is quite different. The oil lies in minute interstices. The oil-water interfaces are a balanced pressure system within these capillaries. The pressures due to surface tension produce a balanced surface of oil, entangled in the sand and surrounded by the water medium. Physically it is true that not only is the oil surrounded by water, but it is interlaced by water, as films on the sand grains which are primarily wetted by water. Such a system is internally capable of adjustment to any form of capillary surfaces, but there will be no change in the centre of gravity of each oil mass unless or until there is a movement of the general medium, *i.e.*, water movement produced by an external pressure. Even in this case, particularly in the finest of rocks, an intercalated oil patch (as apart from a simple globule) is not easy to move on account of the small capillaries, though it would move more readily in a sand provided there was definite movement in the surrounding water.

The gradual accumulation of separate oil patches into fewer larger ones is simulated sometimes in capillary tubes during changing pressure gradients in the medium, but it ceases when the external pressure ceases, and surface tension alone is incapable of continuously shifting the centre of gravity of an oil drop completely enclosed in a water-wet sand. For this reason, surface tension can be ruled out as a driving force in migration. It must be remembered that the normal conditions of oil migration must take place in water-wet rocks. The possibility therefore of absorption and adsorption of oil by dry rocks is ruled out. The

phenomena of oil filtration and adsorption brought up by Day in his discussion of Washburne's theory are undoubtedly applicable to certain phases of oil movement, but they are not governing forces and therefore need no discussion here.

Hydraulic Theory.—An external force capable of producing oil movement which has gained many adherents is that of a moving water column. This was first discussed in detail by Munn and fully elaborated by him in his well known Hydraulic Theory.[8] Primarily he appears to have considered the movement as initiated by compaction, but the main stress of his contention lay in the emphasis of a mobile water column. The oil floated on this column when the latter stabilised, like a timber raft on a river, and became eventually segregated as an oilpool in this state of adjustment. In the case of water withdrawal, the sinking of the oilpool kept pace with the water withdrawal, and the oilpool followed the water table. The view that oil is carried into the reservoir by flotation on moving currents of water has gained many adherents, and is supported by much geological evidence, but this side of the subject will be dealt with more fully in the section on Secondary Migration.

Most of the evidence deals with the movement along and within the coarse rocks. Water columns in the fine rocks have not received general recognition; though Rich considers that these exist and are the primary causes of all migration.[31] In the compacted state of such rocks, movement of water must be exceedingly slow, if not altogether non-existent. The pores within the rock masses will scarcely be more than ·0005 mm.; the pressure gradients are seldom large. It is the pressure gradient along the capillary which is the ultimate force producing motion, and the presence of oil and water within the capillaries would tend still further to prevent movement, even of the included water.

On the whole, therefore, hydraulic currents in fine, compacted rocks appear to be unlikely causes of migration, but in the porous rocks they have a very important function.

Fluid Currents due to Compaction.—It is probable that the high pressures in many oil reservoirs reflect similar or even greater pressures which exist or have existed in the fine rocks around. These pressures require explanation, and the true explanation probably entails the clue to the motive force of migration. The pressures increase in depth, and in many cases roughly correspond with the hydrostatic head, but there are so many exceptions to this that the cause of the pressure is obscure. It is probably the result of many factors and may not always be the same in different cases. However, the fundamental difficulty in oil migration is

not only the cause of the pressure, but is how this pressure can cause oil movement through rocks which are impervious. This is the difficulty which is seldom faced by writers on the subject. It is true that there are many shale bodies which by virtue of joints and bedding planes could allow oil passage under pressure, but there are, on the other hand, great bodies of homogeneous soft clays, with only minute capillaries. Even these are water-wet, and through them oil movement would be almost impossible. The problem of how the oil could have passed through such bodies to the sands they enclose seems almost insoluble so long as we infer that the migration occurred while the clays were in their present form. Once, however, we admit the phenomena of compaction, the position is altered. The weight of overburden, and later on lateral pressure, squeezes the sediments finally to about one-fifth to one-sixth of their original bulk. This means that from four to five times their final bulk must be expressed in the form of fluids in the course of time. This process begins early, in fact immediately after sedimentation occurs. The expressed fluids pass through the compacting clays away from the position of greater stress, *i.e.*, usually upwards. The sand bodies within the compacting clays have very important functions. The permeability of such sands is very great compared with the clay masses, therefore their pressure gradients are negligible and their pressure corresponds with the pressure of the immediately surrounding clay layer. Hence fluid movements tend to converge towards the sand from the surrounding clays, save at the one point of low pressure which acts as an exit for fluids. Usually this exit is at the highest point. Thus there is a continuous passage of fluids from the more compacted to the less compacted sediments, the fluid movements being guided by the permeability of the rock mass. These movements in some cases are so strong that they produce structures in the clay mass and can even transport sand grains through the clay. The more common condition is, however, a general slow sweating of fluid upwards. At a later stage the normal compaction gradually dies down and probably it is killed, not by lack of voids, but by increased impermeability, which becomes capable of preventing further fluid movement at the pressures available. At this stage there are two possibilities which may restart movement. Fracturing of the formations with local increase of permeability, or lateral earth stresses which increase the pressure sufficiently (and possibly increase permeability locally) to restart movement in spite of the high resistance.

The changes in porosity due to compaction are indicated in a rough way by the graphs of Hedberg[41] showing the effect of pressure

on a sediment, and these indicate the range of porosities with depth in similar rock types. Whether oil is formed early or late in the stages of compaction it will, with the associated sea water, form part of the altering system. If it is formed so late that it escapes almost entirely the stages of compaction, it is the writer's opinion that the whole phenomena of oil concentration becomes infinitely more difficult to explain. There is no adequate cause save that of compaction and lateral stress, which will explain all the phenomena of primary migration in a satisfactory manner. It is for this reason, more than any other, that the author feels compelled to conclude that the time of oil generation is early in the phase of sedimentation, a conclusion to which many authors have been driven by entirely different lines of reasoning.

In the expression of the fluids from the clay substance by compaction we have probably several phenomena governing the type of fluid movement. The clay is primarily water-wet, its affinity for oil in such conditions is small, so that adsorption is probably negligible. On the other hand the expressed fluids, both water and oil, have different viscosities. The more mobile water may move the faster and by-pass the oil to some extent. In fact it is probable that the fluids which are pressed out initially are entirely water, and that this salt water becomes richer in oil in the later stages of compaction. The expression of the water clays has been proved by various authors, including the writer, but the details of the process still require working out. The conditions are complicated by the fact that we have two or three (if gas is there as free gas) separate substances passing through capillaries, though they are not capillaries in the normal sense of the term. Rather it is a felt mass of particles with fluid lying between and around the solid grains. Gradually this felt gets closer in its texture and the passage of fluids more and more hindered.

The history of the Primary migration is not complete until we have safely traced the oil from the source rock to the reservoir rock. In the writer's opinion no explanation of Primary migration is satisfactory unless it explains :—

(*a*) How the oil moves from the source rock to the reservoir rock.
(*b*) Why, having reached the reservoir rock, it is trapped there.
(*c*) How the water-oil mixture of the source rock, in which water predominates, can become a rich oil in the sand.
(*d*) How the oil separates from the water in the process of migration.

We have attempted to summarise the conditions governing the movement from the source rock to the reservoir rock, but the other three factors demand explanation.

Filtration of Oil from Water Current.—The trapping of the oil in the coarser reservoir rocks is one of the most difficult problems. Munn's Hydraulic Theory is admirably clear and logical until it comes to this difficulty, but then it becomes vague and unsatisfactory. In order to clear up this point the writer undertook a quantitative examination of the movements of oil and water in water wet and oil wet capillaries, and particularly the pressure systems involved at the oil-water interfaces in these capillaries. The results of these experiments are very illuminating, for they show that in a water-wet capillary there is a definite back pressure set up when the oil attempts to enter, and unless the pressure in the fluid is able to overcome this resistance the oil cannot penetrate the fine capillary. Now it is quite true that in reality the pore spaces of sands and clays are not true capillaries, and in some respects it is fallacious to argue from the behaviour of liquids in true capillaries when discussing these phenomena, but in the movement from a fine rock to a coarse rock or *vice versâ* it is legitimate to consider the phenomena as strictly comparable to the movement from coarse and fine capillaries. For this reason the first experiments were made with a single capillary, and results were confirmed later on sand bodies.

Experiments on Capillary Pressure Systems in Oil-Water Mixtures.

(*a*) *Water-wet Capillary.*—A water-wet capillary tube was connected to a head of water and immersed horizontally just below the surface of some kerosine. The head of water was then altered to obtain the pressures (*a*) at which the water was extruded from the capillary to form drops, and (*b*) at which the oil began continuous penetration of the capillary. The pressure heads due to the oil and water were then noted, and the necessary pressure to produce extrusion of the water and intrusion of the oil was found.

(*b*) The experiment was repeated with a water-wet capillary connected to a head containing kerosine and immersed horizontally in water. (See Fig. 1.)

It was noted in this experiment that in the retraction of the oil within the capillary the oil column became broken up into drops and irregular columns, and that these drops increased the resistance to movement and produced a cessation of flow, unless or until the pressure head was altered to overcome this resistance. This occurred both during water intrusion and oil extrusion, and in some cases the normal back resistance was increased threefold. (See Fig. 2.) This indicates, incidentally, that droplets

of oil in a water capillary tend to inhibit movement and produce static conditions.

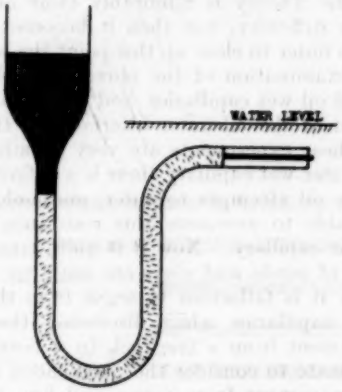


FIG. 1.

Oil-wet Capillaries.—The two previous experiments were repeated with oil-wet capillaries, and the result of the four experiments are tabulated below in the form of the minimum pressures necessary to produce continuous movement—*i.e.*, to break down the resistance of the oil-water films at the entrance to the fine capillary. This entrance can be considered as the interface of a narrow capillary and a large one.

Results of Experiments 1 *and* 2.

Diameter of Capillary = 0·60 mm.

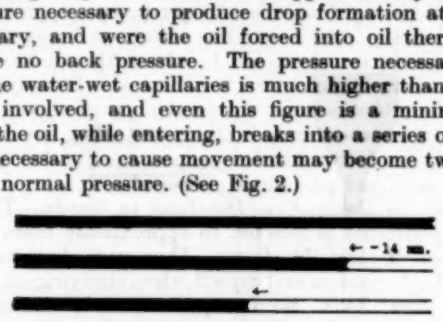
	Water-wet capillary.		Oil-wet capillary.	
Extrusion Pressure	Water into oil 0. mm.	Oil into water 16·0 mm.	Water into oil 0. mm.	Oil into water 17·5 mm.
Intrusion Pressure	Oil into water 24·0 mm.	Water into oil −14 mm.	Oil into water 17·0 mm.	Water into oil 7·7 mm.

Diameter of Capillary = 0·03 mm.

	Water Wet.		Oil Wet	
Extrusion Pressure	Water into oil 1·0 mm.	Oil into water 14 mm.	Water into oil 1·0 mm.	Oil into water 21 mm.
Intrusion Pressure	33 mm.	56 mm.	21 mm.	45 mm.

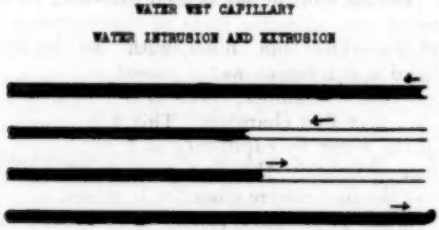
In nature the normal conditions will be water-wet capillaries, so that attention may be restricted to the first set of experiments. It will be noted that the water columns have little difficulty in passing out of or into the fine capillaries in this case. On the other

hand, it is seen that the pressure necessary to force an oil drop out of the fine capillary into the water is approximately equivalent to the pressure necessary to produce drop formation at the end of the capillary, and were the oil forced into oil there would, of course, be no back pressure. The pressure necessary to drive oil into the water-wet capillaries is much higher than any of the pressures involved, and even this figure is a minimum figure, for when the oil, while entering, breaks into a series of drops, the pressure necessary to cause movement may become twice or three times the normal pressure. (See Fig. 2.)



WATER WET CAPILLARY

WATER INTRUSION AND EXTRUSION



OIL WET CAPILLARY

WATER INTRUSION AND EXTRUSION

FIG. 2.

The gist of the preceding considerations may be put more clearly by saying that there is no difficulty for the water to enter the fine water-wet capillaries; but there is on the other hand a strong resistance to the oil passing into such capillaries.

The experiments were carried out with capillaries of 0.6 mm. and 0·3 mm. diameter. Capillary pressures are inversely proportional to the diameters of the capillaries. Hence, if we accept

the figure of 0·01 and 0·0001 mm. as an approximate estimate of the average pore diameters in silt and clays respectively (these are actually arbitrary figures, but they represent approximations), the back pressure of the coarse-fine interfaces between sand and each of these constituents would be about 3½ and 350 lb. to the square inch. These figures need not be taken literally, but they serve to indicate that a very considerable pressure is necessary to force oil into water-saturated clays, and they are a sufficient indication of the factor which is responsible for holding the oil back in the sand and preventing dispersal.

Experiments on Coarse-Fine Interfaces in Sands.—The second group of experiments is selected to approximate more closely to the conditions of sand interfaces. They were done many years ago by Mr. C. A. Sanson and myself when studying oil and water movements, and have been repeated and confirmed. The apparatus for the experiments consisted of a long glass tube, 7 cms. in diameter and 20 cms. long, fitted with rubber corks containing a single inlet and exit tube respectively. These tubes penetrated past the corks, and their ends were covered with gauze to prevent choking. The inlet tube was connected to a source of oil and water under pressure which could be finely adjusted to regulate the flow of oil and water independently. The tube was filled with coarse and fine sand in alternate chambers, the first and last chamber being coarse. Care was taken to ensure complete compaction. The sizes of the sands used were 8 to 12 and 50 to 80 I. M. M. screen.

Experiment 3*a*.—The tube filled with dry sand is set up horizontally and a current of water passed through. The water enters the first coarse chamber, sinks to the bottom and flows to the base of the first fine chamber. This is immediately wetted and draws up the water by capillarity as it comes from the coarse chamber, until ultimately the first fine chamber is filled with water, whereas the first coarse chamber is air locked, save for the basal stream. This process is repeated in each group of chambers up to the outlet tube where the water overflows.

The writer does not wish to dwell on the features of this experiment save to point out : (*a*) the significance of the action of surface tension at the coarse fine interfaces, and (*b*) to note the trapping of the gas.

Water-Wet Sand.

Experiment 3*b*.—The second experiment was performed with the same apparatus, but the sand in the tube was impregnated completely with water. The experiment was carried out using a current of 90 per cent. water and 10 per cent. oil, as the invading fluid. The path of the invading water could not, of course, be

seen, but the oil was observed to spread rather irregularly in the first coarse chamber, more being in the upper part than in the lower; but the division was not good. No oil penetrated the first fine chamber, and it was not until the oil apparently filled the whole of the first coarse chamber (save presumably a basal current of water which was continuously passing) that the oil suddenly proceeded to invade the boundary of the first fine chamber across the coarse fine interface. Slowly the upper part of the oil current gained ground and reached the second coarse sand first. As soon as it did so further invasion of the water

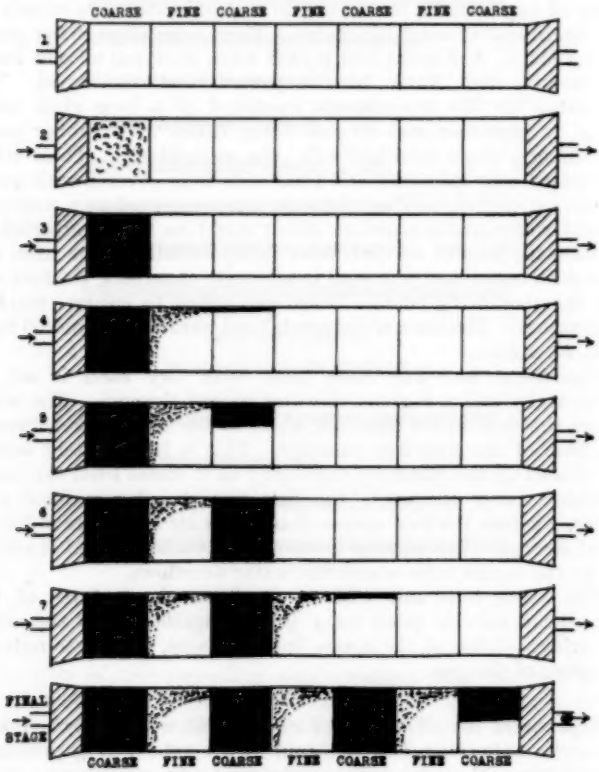


FIG. 3.

OIL TRAPPED IN COARSE SAND BY PASSING A 10 PER CENT. OIL, 90 PER CENT. WATER MIXTURE THROUGH A WATER-FILLED SAND.

saturated fine sand ceased and all oil movement was directed along the upper stream. It filled the second coarse chamber from above downwards in perfect hydrostatic separation and did not invade the second fine chamber until the coarse was filled. The rest of the experiment proceeded on the same lines and is indicated by the attached diagram. At the end of the experiment the volume of water which had been passed through the tube before the first drop of oil appeared at the exit was equivalent to 4·2 times the pore space in the sands. The oil trapped was nearly 50 per cent. of the total pore space, and practically filled all the coarse chambers save the last, which was only partly oil filled. (See Fig. 3.)

It may be argued that this is but a question of the greater surface tension of water whereby the oil is retained in the coarse and the water invades and holds on to the fine sands; but that this is not so can be shown by the following experiment.

Experiment 3*c*.—Experiment 3b is repeated, with, however, the

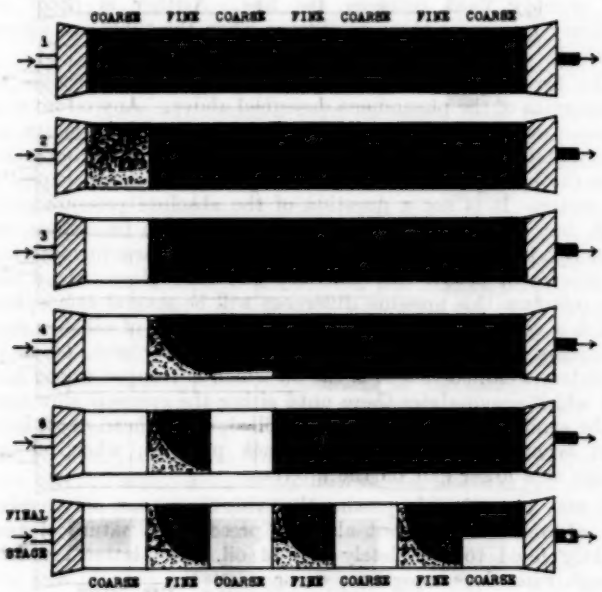


FIG. 4.

WATER TRAPPED IN COARSE SAND BY PASSING A 10 PER CENT. WATER, 90 PER CENT. OIL MIXTURE THROUGH AN OIL-FILLED SAND.

fluid conditions reversed. The sand was filled initially with oil and a 90 per cent. current of oil and 10 per cent. of water passed in. (See Fig. 4.)

In this experiment the water behaved just as the oil had previously done, filling each coarse chamber to the edge where it abutted against fine sand. The only difference was due to the flotation of oil on water, whereby the chambers were filled from below upwards, and the water, when it did penetrate the fine, passed through more rapidly in the lower zone. Another obvious difference was the longer time taken, due to the greater viscosity of the 90 per cent. oil mixture.

The experiments are shown graphically in the accompanying figures.

The results of experiment 3c show conclusively that it is not the result of a higher surface tension which causes water normally to drive oil to the coarser rocks. In all these experiments it is the secondary fluid which always occupies the coarse rock, while the primary fluid occupies the fine. Neither is there any tendency to reverse these conditions when the tubes are allowed to stand.

The first experiments with the single capillary provide the explanation of the phenomena described above. Any oil invading a coarse water sand from a fine clay can do so with impunity, but immediately it attempts to pass out of a coarse into a fine sand it faces the back pressure of the fine capillary surfaces occupied by the water. It is not a question of the absolute pressure in the sand, but of the pressure gradient between the two sands, and while this is less than the back pressure at the coarse fine interface, no movement across the boundary can take place. In a sand clay interface this pressure difference will be several atmospheres and is a complete explanation of the retention of oil in a sand. In nature our formations are primarily water wet, oil is the secondary fluid, so that it is the oil which is trapped in the sand, and which accumulates there until either the currents slow down or the sand becomes completely oil filled, or the head of oil in the sand becomes greater than the back pressure, when oil may escape at a lower exit on the interface.

It may be noticed in passing that this theory not only explains the oil concentration, but also the presence in nature of sands slightly filled to completely full of oil. The latter condition, though rare, does sometimes occur.

In the discussion, the behaviour of gas is avoided to simplify the issue, but the gas-oil, gas-water, and oil-water boundaries act in the same way, save that the gas and oil are mutually soluble.

The importance of the primary wetting material and of the principles set out above have been partly realised by a few previous experimenters, but somehow the significance of their work has been overlooked. In 1922 Dodd published the results of his experimental work wherein he concluded that normally capillarity resists movement, but that in moving water-oil-gas columns surface tension played a part in guiding concentration.[33] Another publication of the same year by O. W. Skirvin[32] was still more specific in that he shows that oil-wet fine sands tend to keep out water, whereas water-wet fine sands tend to keep out oil. He shows that the normal theory of capillarity fails to explain these points and considers that it is partly because in an oil-wet capillary there is no capillary attraction for water and partly it is a function of the adhesion and viscosity of the oil. Skirvin concluded, as the author has done, that the invading or secondary liquid is always found in the coarser rock, but he did not realise the nature of the influences at work at the coarse fine interfaces which produce this result.

Among the experimental investigations carried out in America on the movements of oil, gas and water, some of the most illuminating, in the writer's opinion, have been those described by Van Mills and carried out in the laboratories of the U.S. Bureau of Mines.[29,30] These experiments were on sandy beds of different coarseness deposited in a tank with glass sides. Oil, water or gas could be pumped in or extracted at will through taps and inserted tubes in the bottom, sides and tops of the tank. A large number of experiments were carried out in these tanks to study the flow movements of gas, oil and water in different beds in different structures and under different conditions. Flow conditions and static conditions were examined and, lastly, work was done on oil extraction from reservoir sands. It was with somewhat the same type of apparatus that the writer intended working some ten years ago, but when Van Mills' work was published it became unnecessary to continue this investigation, particularly as the excellent photographic reproductions enabled the reader to grasp clearly the results obtained.

Yet it is surprising that Van Mills himself did not apparently realise the full significance of his own results and was not driven to consider in greater detail the physical reasons for the effect of texture on migration to which his experiments bear eloquent witness. In essence they are a complete justification for the views put forward in the preceding section. In several cases Mills stresses the importance of texture, shows that the oil followed the coarser rocks and stopped at the boundary of the fine rocks. His photographs illustrate the principle admirably,

showing the complete subjection of movement and accumulation to the guidance of texture. In one case, where the gas and oil accumulated in an arch within a coarse sand at the base of a fine sand, he explains that the accumulation proceeded normally and then eventually the gas and oil burst through the interface and moved onwards to the next coarse sand. This accumulated pressure obviously overcame the back resistance, which would not be high between a coarse and fine sand, particularly as his pressure gradients in such a small apparatus were much greater than would be true in nature. With a clay mass resting on a sand the pressure holding back the oil would have been much greater, and it must be remembered that in nature the vertical pressure gradient is probably only about ½ lb. per sq. ft. initially, and is only about double this when compaction has taken place. On the other hand, Mills in a small tank used pressures up to 40 lb. per sq. in. and pressure gradients therefore much greater than nature provides. Even so, the oil followed remarkably the influence of rock texture and acted on the principles detailed above.

Conclusions.

Primary Migration is considered to be the result of the compaction of the source rocks, firstly by settlement and later by lateral pressure. It is considered that oil is formed early in the sedimentary cycle and that the process of rock compaction is a prolonged episode. The liquids so expressed consist largely of salt water carrying some oil, and both fluids pass together into the sand bodies. However, the fluids which pass out of the sand bodies are filtered of their oil by the water-wet coarse-fine interface where the sand meets clay. This process of filtration is comparable to the use of a wet filter paper in the laboratory to hold back a fluid immiscible in water, and for this reason it is suggested that the process of segregation at the coarse-fine interface be called *Filtration*.

It is impossible for the oil to pass out unless it can develop a local pressure gradient greater than the necessary pressure to burst the oil water film at the boundary of the fine grains. This leads to the accumulation of the oil near the exit, and is the first stage, and sometimes the whole process, of producing an oilpool. It is emphasised that it is not the absolute pressure, but the pressure gradient at the coarse-fine interface which determines whether oil can or cannot pass into the clay.

Secondary Migration.

Buoyancy.—In the previous section it has been shown that the oil-water currents due to compaction enrich the sand bodies

with oil. Our next study is the segregation of this oil from the salt water within the sand body and its retention in certain special parts of the structure, usually the highest position that it can attain. It is usually considered that here, at any rate, we are on safe ground in assuming that the oil would sink in dry rocks and rise in wet rocks. In porous rocks with open joints and bedding planes, or in rocks with pores sufficiently coarse to give very little capillary pressure, there is no doubt that it would. Indeed, experimental evidence proves that gravity separation can take place in a very coarse sand under static conditions. At higher temperatures the difference in surface tension between oil and water tends to disappear, so that gravity separation may become possible even in medium grained sands. Yet the writer is inclined to have very grave doubts whether gravity separation in the static state is usual in oil sands, save in coarse or well jointed and fissured rocks. It is unsafe to argue sweepingly, for the conditions will depend entirely on the form of the porosity, but there are some fields where gravity separation obviously does not exist. One good instance is Cushing in Oklahoma, where the oil-water surface of each of three Pennsylvanian sands is inclined at the ends of the structure. This inclination was found when the fields were opened up, it is the same in each sand—*i.e.*, downwards towards the west. There can be no doubt that in this case the inclined oil water surface has remained so over whole geological epochs, and there is nothing in the local structure to explain the departure from horizontality. The explanation offered by Beall[12] is that the dome trapped oil advancing from the west, and that the oil and gas, in attempting to work around the structure, was flushed out more effectively at the two ends leaving the inclined surface. There are many other similar cases of inclined water tables which leave no doubt that static gravity separation is not a universal and may not be the normal condition in the oil rocks. This conclusion is supported by many authorities both on field and laboratory evidence.

Water Currents.—R. H. Johnson, in a discussion of Washburne's paper on "Capillary Oil Concentration," laid stress on the importance of movement in oil separation.[13] In doing so he undoubtedly laid his finger on the core of the question. Munn based his hydraulic theory on the power of moving water columns to segregate oil, and others such as Shaw, Rich and Dodd have championed this part of his case.

Some years ago the writer conducted a series of experiments which clearly show that under moving conditions oil will separate over water, or is even able to pass through and over a water current in a fine sand.

Firstly, it may be explained that tubes containing water and kerosine in fine and medium grained sands were kept in the laboratory for three years, and it was shown that no movement took place. In these experiments the oil was introduced below the water, and in other cases intermixed with it, yet no tendency to change was noted. The reasons for this stability are undoubtedly due to the fact that the relative buoyancy of the oil masses is insufficient to overcome the surface tensional effects of the oil water interfaces surrounding each oil patch. Thus no movement is possible. This vital objection to gravity separation has been often stated, and readers are referred to works of Munn, Washburne, McCoy and Dodd, etc.

Experiment 4*a*.—In a group of experiments to study moving currents of water and oil in sand, a long glass tube was packed with sand and saturated with water. At one end there were two inlet tubes which were deeply inserted into the sand, and at the other end two outlet tubes similarly inserted. The upper inlet tube was connected to a water supply, while the lower one was connected to a head of kerosine. The pressures from these two supplies were adjusted to be approximately equal, and the fluids were allowed to pass into and through the sand in the tube. After a short period, when the first drops of kerosine were noted in the delivery tube, the fluids delivered from the upper and lower exit tubes were collected in separate measuring cylinders and the quantities of kerosine and water separately measured.

It was found that the larger proportion of the kerosine was delivered from the upper tube, whilst the water tended to accumulate in the lower tube. The separation was not perfect, but it was found that if the sand tube was lengthened so that the length of journey increased, the separation became much better. Also, it was found that the same separation occurred in both fine and medium sands, and apparently to the same extent. Here, then, it was shown that moving currents of oil and water were able to separate according to their density, and that the lighter fluid, if introduced below the heavier, was even capable of crossing it.

A little examination of the conditions of the flow will demonstrate how this separation takes place.

In the movement of the fluids through the sands there must always be zones where the moving oil and water come into contact. Such contact surfaces as they pass between the sand grains become turned in the narrow chambers into a successive flow of oil and water or water and oil. Now the chambered surface between the sand grains is very irregular, but can be considered roughly as spirals with an upward and downward trend and with intercommunications in each direction. Thus the oil and water in

moving forward have repeatedly an upward or downward choice. Oil following water tends always to choose an upward passage, for the front lobe of the oil mass bends upwards as it enters the wider zone of the chamber. Water following oil, on the other hand, tends to turn downwards. If free droplets of one medium in the other are forced into the wider portions of the chambers the drops rise or fall according to whether they are the lighter or heavier liquid. Hence during the forward movement gravity separation occurs. This proceeds whether the sand is fine, medium or coarse, and in the fine sand the larger number of chambers possibly makes up for the more restricted movement in each chamber. There is possibly a downward limit of size at which the process would cease, on account of the increase of capillarity, but it has been shown to occur in the finest of sands available.

Some Applications of the Theory of Water-Oil Currents.—Armed with this conception of the separation of oil over water in moving conditions we may apply it now to the picture drawn in the previous section of a moving column of water and oil passing into and along the sand bodies. It can be readily seen that in such a system the oil (and gas) would choose the upward journey and the water the lower one, towards the position of lowest pressure, *i.e.*, the general zone of exit from which the water was being expelled. Hence the oil and gas would gradually increase in concentration in the upper parts of the sand body, and there would be a continuous feed of such material to accumulate and stagnate just behind the point where the water passes out of the clays. This would be just below the oil water surface. The inclined oil water surface in this presentation would represent the moving conditions of the fluid column, and when movement ceased it would be preserved if the rocks were not coarse enough to allow static gravity separation. The writer would anticipate that the latter would be particularly hindered if the reservoir rock were divided into beds of varying coarseness.

We have abundant evidence that many anticlinal forms were already initiated during sedimentation. In this case oil accumulation on the crest would automatically arise as the compacting currents carried oil and gas to the highest part of the structure. On a lens flanking a fold, the oil and gas movement would be to the upper part of the sand lens. In the case of a structural terrace on a monocline movement is generally up the regional dip. In the neighbourhood of the terrace the oil stream would tend to converge towards the latter athwart the water stream, because the oil would always choose locally the highest path. The steepened dip on the flank of a terrace provides this. The convergence of this oil towards the terrace flattening would produce a fluid of

greater average viscosity than the general fluid, tending to slow down movement in the heart of the terrace. This would produce a feature somewhat like a back-eddy in a river. Into this zone the oil would tend to rise from the steep flanks at the expense of the water and the terrace would become gradually filled with oil, just as a back-eddy in a river may become filled with floating timber. The writer contends that this explanation is more in keeping with physical laws then the theory that a terrace represents a zone in which the dip is too gentle to allow the water to carry the oil along. It can be proved readily that water currents can flush oil downwards as well as upwards, though not with the same facility, and something more is required than this simple explanation for a terrace pool. The writer believes that it is not only the flattening on the terrace, but the inevitable steepening of its flanks above the general regional dip, which is the vital factor. In this connection it is worth while referring to the importance of any local steepening, and such structures as monoclinal ravines or noses have a new significance when viewed in this light. The local steepening has gathered the oil supply, the greater viscosity of this mixture has retarded movement, and a general sluggish zone has been formed in the line of movement. Into this zone oil is washed upwards while water is displaced downwards in the slow movements of adjustment due to the general pressure gradients.

It is being realised more and more that the study of the sea floor conditions associated with the formation of the sand bodies is of supreme importance in the explanation of some of the oil-pools. Particularly is this so in the case of some of the sands of the North and South Mid-Continent. Sand bodies on old shore lines covered ultimately by fine textured rocks form ideal traps; for the moving currents pass into these bodies from all sides and pass out mainly from their upper, shoreward ends. The coarse-fine interfaces at such ends hold back the oil but allow the water to pass onwards.

Gas as a Medium of Oil Flotation.—Other influences are no doubt at work in this differentiation of gas, oil and water in a porous reservoir rock.

The influence of gas is probably of much importance in helping separation. In the case of some open sands, gas may help to raise the oil through the water under static conditions. The importance of this action has been strongly stressed by R. H. Johnson, [27, 28] though Dodd's experiments did not support static separation with the help of gas.[33] This vehicular action of gas is the result of its low density and affinity for oil, and provided the gas is not all in solution it will undoubtedly help both static and mobile separation. Such gas is also unable to escape at the

coarse-fine interface and accumulates there. Further, there can be no doubt, as has been specially emphasised by Van Mills, that alterations of pressure within an oil-gas mixture cause considerable alterations in the amount of gas in solution. Unless there is some compensating influence whereby the amount of gas is replenished by more gas formation, the relative amount of free gas should diminish during the flow of the compaction currents. However, at the present stage of our knowledge, it is difficult to speculate with any degree of assurance on this point. Later on in the history of the cycle, when denudation, folding, faulting and changes in temperature affect the reservoir, there can be no doubt that the medium which reflects these changes with the greatest delicacy is the gas, and these readjustments cause considerable changes within the pool; but they are too varied to be considered here in detail.

Effect of Viscosity.—One further feature of the oil and gas which must be taken into account is the viscosity. Unfortunately we know very little about the relative behaviour of immiscible fluids in terms of their physical constants when passing through capillaries or through sands. It is not certain whether we can treat the fluid column as one whole, or whether the materials retain a sufficient individuality to flow according to their own physical constants. It is more likely that the gas and oil retain a certain individuality, but that the fluids as a whole have certain bulk characteristics. These will change as the oil and gas separate out. The oil zone will be characterised by high viscosity, the gas zone by great mobility; and the writer can visualise conditions, particularly in very extensive sand bodies and gentle structures, when these two materials may become completely separated. This is much less likely to occur in folded country where structures set a limit to regional migration. This may be a clue to the abnormal separate existence of great gas fields which is so typical of the Palaeozoic rocks, though it is true that gas fields exist elsewhere. In any case the high viscosity of the oil zone will undoubtedly produce a mass inertia which will cause fluid flow to skirt it and thus prevent its dispersal. An oilpool would thus become in itself a block to migrating currents, its boundaries would probably receive more oil than was taken away at the exposed parts of its exterior, so that an oil accumulation once forced would tend to grow.

Conclusions on Secondary Migration.—In dealing with the migration within the reservoir rock I have not attempted more than an outline of the physical influences at work. To have dealt with the subject adequately would have meant lengthening the paper to an unreasonable extent and charging it with numerous

examples which would have complicated the issue. My aim has been to look at the problems of the oil geologist from a physical point of view and attempt to utilise both sciences in my explanations. There is a vast amount of accumulated knowledge in geological literature on the subject which requires careful selection. There is also in the literature and in current usage a considerable bulk of pseudo physical explanation which would not dare to live in the cold light of adequate critical examination. As an instance the views of capillary oil migration current in American literature are curious in the extreme. The experiments brought forward in their support do not bear examination. Amid the welter of accumulated opinions, based sometimes on sound observations, but more often on sweeping generalisations after inadequate study, the student must be forgiven if he reaches the final conclusion that the whole subject is wrapped in mystery. It is not so much mystery as fog which surrounds it, and the writer hopes that in putting forward his views he has not added to the literature one further misleading contribution.

In his view there is no single influence which governs oil migration within the reservoir rocks, unless it be that moving currents initiate the separation of oil and gas over water, and are probably the most important agents of separation. Of one influence, however, we may be sure, for it is instanced in almost every pool. Rock texture is of extreme importance. The guiding feature which causes this is not permeability, but is the influence of the coarse fine interface. It must be remembered, however, that the form of the porosity is a very variable feature in such rocks. In some the pores are fine, in others they are coarse. In some reservoirs there are important joints and fractures, in others there are none of these features. We cannot, in the face of such varying conditions, either assert that static buoyancy is a complete explanation of the conditions found in all pools, or deny that it exists. It probably can function in some areas and not in others. Further, there are other features such as gas lift and viscosity which must be taken into consideration. The final limits of the pool may therefore be due to many influences.

General Consideration on the Migration Processes.—An adequate treatment of migration ought not to omit the consideration of such fundamental subjects as the limits of possible migration and its general direction, upwards, downwards and regional. These are fundamental to our study of oil regions, but they would require a separate paper.

My observations on them will be brief and are meant rather to invite discussion. One has only to turn to the subject of source rocks and realise how varied are the views of geologists on the

possibilities of migration. To some it is unlimited, to others it is a strictly local and restricted phenomenon. The following points seem pertinent to the writer. (*a*) The permeability of the clay rocks is relatively high at only one stage in their history, when they are young. At this stage they are permeable largely because of their sponge-like nature. Therefore logically the only way oil could readily pass through a great mass of clayey sediments would be by upward migration wherein the oil was passed on always to less compact rocks. By this process I could conceive a feed of oil through a great vertical thickness of sediments, provided they were not so highly charged with sand that the oil was filtered out, and provided there was a surplus of oil to supply the inevitable retention of some oil in the clay rocks.

For this reason I feel that in general upward migration is much more widespread than downward migration.

Normally within the compacting sediments I see no influence which would inhibit migration. Adsorption may occur, but is unlikely in a water wet medium. Some retention is bound to take place for the compacting process still leaves a percentage of voids. The process is not filtration such as Day visualises, but a squeezing out of fluids in a water wet medium, like the squeezing of a sponge. The flow will be from zones of high pressure to those of low pressure and in the compacting rocks this is mainly upwards. Lateral movements of fluids are probably only in the coarser rocks, hence the importance of regional migration towards the shore lines.

The governing feature which directs all migration is permeability. In compacted rocks this is more variable than any other feature. The permeability of a sand with pores of average diameter of 0·1 mm. is many thousands of times greater than the permeability of a clay. Some writers appear to allow unlimited powers of upward and downward movement of the fluids in the sedimentary crust. Surely this is negatived largely by experience and by the physical probabilities. A competent and porous rock, so long as it can stand up to the earth pressures, can carry fluids down to any reasonable depth. But the beds in oil fields are in the main incompetent, and the preponderance of clay they contain, if not completely stopping flow, limits it to small proportions when compaction ceases. The high saturation of deep water brines in oilfields makes such ideas of a general hydraulic movement suspect. One must clearly differentiate between movement across clay beds and within sands or limestones. So far as lateral and vertical oil migration is concerned the writer believes that porous bodies trap oil from the migrating fluids at an early stage and inhibit further dispersal, unless and until the effectiveness of the seal is broken.

(*b*) Lateral migration in permeable rocks is proved by normal

artesian conditions to be extensive. It is probable that joints and bedding planes play a very large part in even a fine permeable rock, and this is still more true in the limestones and cemented sandstones. In such cases normal gravity separation probably occurs. Some of the large limestone fields show true hydrostatic adjustment and suggest widespread permeability. In such rocks and on suitable monoclines lateral migration may extend over regional limits and in them the suggestive theory of Hewitt and Lupton[19] on regional migration assumes great importance. In many oilfields the sand bodies are small, lateral migration can, therefore, be only very limited and the oil is probably of local origin.

(*c*) The incidence of fractures is of great importance in water movement, oil movement and gas movement. The degree of freedom of movement is obviously a question of the fracturing, and also of the nature of the rocks involved. Thus we find in nature open faults and sealed faults. Faults in which oil or semi-solid bitumen seem to have moved and become consolidated, faults in which the fractured rock system gives abnormally high yields in the fortunate wells which penetrate them. Other faults however have formed such perfect seals that they have been blocks to migration and have become responsible for large oil-fields. In fissured faults water must be considered as well as oil, and it is probable that the oil will move upwards rather than downwards, so that upward migration appears again the more probable.

(*d*) There is, however, one general case of downward migration which appears probable. The deposition of a source rock on a permeable basement, such as a clay on a sandy unconformity, which may lead to downward compacting currents into the basement and along the latter to zones of lower pressure. In such cases overlying beds probably enrich underlying beds and this may lead to considerable downward contamination. In general there seems to be no logical reason for limiting migration to any specific direction any more than permeability can be so limited, but in view of the ever present water saturation and for reasons stated above, upward migration is the more general phenomena.

Another subject of wide interest and on which there is a diversity of opinion is the question of the origin of the pressure. The theory that it is artesian is surely impossible to apply in sand lens fields, and most oil sands are more or less limited lenses. It is the rare exception to find them extending downwards and up again to outcrop. Further, though it is true that pressures increase downwards the results do not agree with expectations on this theory, and the history of the inflow of water during oil and gas exhaustion does not support this idea. There are some fields where the water table moves in sympathy with the pressure during development

and the conditions appear to be artesian. Even these, however, may only be reflected rock pressures in a large body of water entombed underground.

It seems more probable that the pressure systems found in the gas, oil and water are initially due to the pressures superimposed on them in the general compaction of the rocks around, but this is not all. The writer sees in them the effects of the compacting pressures, of lateral pressures, and of possible chemical changes in the oil and gas. They are also modified of course by later physical influences, which have affected the reservoir.

Summary and General Conclusions.

In the foregoing summary of the Migration of Petroleum it has been emphasised that migration is a two-fold process, Primary Migration, which connotes the movement of the oil and gas from the source rocks to the porous reservoir rocks, and Secondary Migration, which refers to the movements and segregation within these rocks, and the final distribution of the oil and gas as pools.

Primary Migration is considered to be due to fluid movements within the source rocks due primarily to compaction helped by any other external or internal sources of pressure. It is held that oil originates while compaction is in progress, and that Primary Migration is in the main completed by the time compaction ceases. At the end of compaction the water wet clay rocks are so impervious that further movement of fluid is largely inhibited.

The accepted explanations that migration of oil and gas is due to Buoyancy, Capillarity or Hydraulic Currents, all break down as adequate theories of primary migration. Munn's Hydraulic Theory appears to be the most satisfactory up to a point, but it fails completely to explain the reason for the retention of the oil in the coarser rocks.

The oil moves with the salt water through the sands or other porous rocks, because these afford the main channels for fluid movements. The oil is filtered from the water in these sands and cannot pass out again into the clay owing to the back pressure to oil at the coarse fine interface.

Secondary Migration, or the separation of gas, oil and water, within the coarse rocks, may in some instances be due to static buoyancy, but is probably in the main due to flotation in mobile fluids. It is considerably aided by gas and is largely guided by the texture of the rock, owing again to the influence of the coarse fine interface. An oilpool once formed is kept in a state of equilibrium with the pressure and temperature conditions in the reservoir.

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DISCUSSION.

Mr. A. Beeby Thompson said that all members of the Institution would be very grateful to Prof. Illing for giving them the benefit of a long series of researches carried out over many years. The author had followed on the lines of other investigators, but had carried his studies further, and had given them all much material for serious thought. He had certainly made out a very good case for the migration of oil through the medium of fluids in motion, and what he had said was more or less in agreement with the views of many modern technologists. One of the greatest difficulties was to reproduce in the laboratory many of the conditions which prevailed in Nature. For example, one could never reproduce the time element, which was a factor of such great importance in geological problems.

He had been particularly interested in Prof. Illing's ideas with regard to primary migration. This was directly related to the very genesis of oil, one of the most contentious questions that could be raised. It was somewhat difficult to understand how oil as such could be formed in the sediments at such an early stage of their existence. He believed that nearly all experiments made on

sediments of comparatively modern origin had failed to demonstrate the occurrence of oil in any considerable quantity. Now and again small quantities of oily substances were abstracted by solvents, but the general impression was that in the early stage there was very little oily material present which could be expressed from the beds. The only case he could recall where the conditions of these sediments were really petrified or fossilised was the landscape marble, where one can actually see streaks containing dark organic matter passing through the limestone, and from which at intervals an evolution of gas had carried some of the organic matter forward and into the upper calcareous layers. In that case the substances forced upward was not oil, but carbonaceous matter.

Again, the erratic impregnation of oil by sands was very difficult to explain Prof. Illing must himself know of enormous masses of sands of which one section was impregnated with oil while another section was not impregnated, or only very slightly, and yet there were no obvious reasons for this selective impregnation.

Another difficulty was to explain why migrating oil by-passed certain competent beds without impregnating them. They all knew how seepage oil reached the surface sometimes from very great depths, and yet within a very few yards of the fissures or faults from which the oil issued, the beds were found practically free of oil.

The limits of natural migration were very difficult to determine. Technologists held widely different views concerning the distances to which oil could migrate, laterally and vertically, and little useful data is available concerning this point.

He wished to ask the author what oils he employed in his experiments. In some cases he noticed the oil used was kerosine, which might behave somewhat differently from ordinary crude oil. Talking of the genesis of the oil and its formation in these uncompacted beds, one was confronted with the difficulty of knowing in what state the oil existed at the time of transference. Some maintained that the first stage was a very heavy product which was eventually converted into lighter oils, while others believed that the reverse was the case and that the original product was a very light oil, which was later transformed into a heavier.

Mr. J. Romanes said that there were very many interesting points on the general question of migration, on some of which he would like to say a few words.

As the previous speaker had mentioned, Prof. Illing at the beginning of his paper had said that the problem of the origin of oil was closely bound up with the problem of its migration.

Similarly it seemed to the speaker that the nature of new-formed oil had an important bearing on what governed migration. In the only case he had personally come across where he was convinced that the oil was of recent formation, it was a very light spirit, but in other cases there appears to be considerable evidence, as Mr. Thompson had suggested, of very heavy products being initially formed, so that the type of oil originating must be an important factor in migration.

He also felt difficulty in agreeing with the rapid formation of oil in the sediments immediately after deposition which the author postulated. He would like to ask Prof. Illing whether he knew of any marked difference in the residual oil content in source rocks in unfolded and folded regions. It seemed to him that if the expression of the oil and the water was primarily due to compaction shortly after the sediments were laid down, there ought to be very little difference in the residual oil content in the source rock in folded and unfolded regions, whereas if the oil and water were driven out by actual tectonic forces, and not by simple compaction, he would expect there to be much more residual oil in unfolded than in folded regions.

There was one other point he would like to raise. If oil was formed at such a very early stage, how were these enormously high gas pressures built up? Was it assumed that whereas oil was formed very rapidly, the residual organic matter went on forming gas so that the pressure was built up after there was sufficient cover of rock to retain it?

He had been glad to hear the author suggest that there might be a further paper on this subject. There was one migration problem of extraordinary interest and importance to all oil geologists which the author had not touched. In primary migration Prof. Illing has shown them the ship leaving port; in secondary migration he had shown its arrival, but he had said nothing about the possible length of the voyage. Was migration simply confined to movement from the argillaceous beds to closely adjoining reservoir rocks, or was there long-distance migration, both vertical and horizontal? This was a matter of great practical importance. In this connection it was interesting to note the change of view which had taken place in the case of the German oilfields. Up to a few years ago it was very generally admitted that in Germany there were definite primary oil horizons in the Wealden, Dogger and Lias, but the recent discoveries of Permian oil below the salt in Thuringia had caused a sudden alteration of view. There had been an almost complete change of opinion among German geologists, who now desired to

explain the higher oils as a migration from that deeper source. Personally he still stuck to the idea of these higher primary horizons.

He looked forward very much indeed to the further elucidation of the process of migration by Prof. Illing.

Mr. E. H. Cunningham-Craig said that it seemed to him, after reading the paper, that it was perhaps more academic than practical, and for the following reasons. It had been pointed out already by Mr. Beeby Thompson that it was quite impossible to reproduce experimentally the conditions in Nature, for example, in the question of time. There was also the question of pressure. They could not get the necessary pressures in experiment, nor could they get the same kind of oil. The oil that was struck in a well at great depth was not the oil which was collected at the surface, and the pressures which had to be dealt with down deep in the ground were very great. Again, the rocks which they examined at the surface, or for a considerable distance beneath the surface, were in the weathering zone, and it was found that they nearly always contained a certain amount of water ; but deep in the earth, where the oil was formed, there was probably very little water in any of the rocks.

Then, Prof. Illing, he was afraid, had begun on premises some of which were very doubtful. To begin with, if there was one thing they knew about the formation of oil, they knew that it was formed under very high pressure, obviously long after the rocks had been compacted and deeply buried. Again, there were very few cases that were found, except in the weathering zone, of the saturation of beds with water. There was probably hardly any rock in the world that did not contain a little water in it somewhere, but when they were dealing with cases of extensive migration, where it could be proved that oil had gone through many thousands of feet of different rock, they found that these rocks were very slightly, if at all, affected by water impregnation. It was known perfectly well that argillaceous rock containing water was very difficult for the oil to penetrate, yet they knew that oil could and did penetrate and even pass through such strata. It depended largely upon the pressure.

The author had not said much about gas, but it was necessary to consider in these things there are not only water drives, but gas drives, though the gas did not occur as gas, but only potential gas. When they struck it in a well, a certain amount separated out as gas, coming up often with great pressure ; but down deep in the earth this was a liquid, it was potential gas, and the driving

force of it must be tremendous, as they could tell at once as soon as the pressure was released, when a well came in.

Another of the premises which he was inclined to doubt, although it was believed by a great many people, was that oil was formed in argillaceous beds. It might be formed there, but it was formed in other kinds of beds too, and to say that it was all formed in argillaceous beds was to beg the whole question.

All the diagrams they had seen were really instances of the phenomena of surface tension. He did not think that surface tension had a very great effect in large migrations of oil over great distances, but the mode by which the oil migrated was under the force of surface tension. It did not migrate in drops, unless it was being borne along by a current of water deep in the earth, a thing, he supposed, that hardly ever occurred in Nature ; it migrated in microscopic films, simply under pressure, no doubt, but the pressure might be of all kinds. It might be a hydraulic pressure, it might be a potential gas pressure, or it might be pressure due to depth or due to earth movement, but the *mode* by which it migrated was by films.

He thought, dealing with the whole subject, that it was perhaps easier to study it in the field than in the laboratory, and he must add that he had never found any difficulty in understanding why oil got where they happened to find it, or why it was not in other places where they did not find it.

Dr. A. Wade said that all would agree with Prof. Illing that the field geologist could not adequately study the problems which he met with in the field without sound conceptions with regard to origin, migration, and accumulation of petroleum. This was of special importance at the present time when new oilfield areas were becoming increasingly difficult to discover. They had got a good way from the idea that the only virtuous thing in the field was a perfect anticline. The present paper indicated that there were a great many other geological structures in which oil might occur. Studies of this kind were bound to broaden the field for the prospecting geologist.

He thought that this paper might very well be read in conjunction with a recent paper by Versluys. That worker had tackled the problem on rather different grounds and by a rather different process of reasoning, but he had reached practically the same conclusions as Prof. Illing. For example, he described the first migration as being due to compaction ; he also dealt with the passage of oil and water through porous strata and the action of the interface between coarse and fine. He also raised some other

points which seemed to the speaker to be complementary to the work which Prof. Illing had presented to them. The experimental work which had been so very adequately demonstrated in the slides and diagrams was, however, lacking.

The speaker was inclined to agree with Mr. Cunningham-Craig in doubting whether all oil originated in the argillaceous sediments. A good deal of field work in many parts of the world had convinced him that in many cases the source rocks were limestones. The Institution had a paper last year by Hackford, which, although it was perhaps very strongly criticised, did put forward some discoveries which might very usefully be considered in conjunction with Prof. Illing's work on the origin and migration of petroleum.

One interesting point referred to by Prof. Illing was the inclined oil-water table in certain oilfields. Beale, Rich, Daly and Versluys had all dealt with that matter in various papers, but on reading those papers he had formed the opinion that variations in porosity, associated with variations in compaction and, perhaps, cementation, affected capillarity and tended to bring about these inclinations in the oil-water table. Those papers were worth referring to in that connection.

In his remarks on gas fields, Prof. Illing had indicated that one might get gas fields only in extensive sand bodies. He thought that that might explain the accumulations of gas which had been found in Queensland.

Another important matter referred to in the paper was the possibility of downward migration of oil. This had not received sufficient attention. Many years ago it was ruled out as almost impossible, but of late years he had come across many instances where he felt almost certain that oil had been migrating downwards instead of upwards, and he noticed with pleasure that Prof. Illing did not rule that out. One very interesting case was that met with in the Ironville well in Derbyshire. A good many people believed that the oil in Derbyshire originated in the Coal Measures, but at Ironville an oil zone was found several hundred feet below the surface of the Mountain Limestone. In the Greek Peninsula, again, there were a great number of occurrences of petroleum in the Eocene-Cretaceous limestone, and in many cases it seemed possible that the oil had originated in the Miocene marls and clays above. A correct interpretation of such problems might be of great commercial importance.

He thought that on this question of migration there was need for the co-operation of the chemist. For instance, over large areas in the Mid-Continent of America, petroleum was met with in a

great number of sands at various horizons, and there seemed to be some general family connection between them. It looked as though they all came from one source zone. The same thing applied in other areas. It was important to know whether these oils were likely to have come from the same source rocks and to have migrated to their present position. In that respect the research chemist might afford a great deal of help.

Mr. T. Dewhurst said that there was no doubt that this subject of migration was one of the fundamental aspects of petroleum geology. Fortunately, Prof. Illing had cut away a good deal of "dead wood" that had accumulated around the subject. However, he had not been content to be merely destructive; indeed, he had been very constructive and had based his arguments and conclusions on the results of many painstaking experiments. These experiments had thrown a good deal of new light on the subject of the migration of oil and one could not do otherwise than accept the results which had been presented so clearly and fully.

In regard to the inferences to be drawn from the evidence, he was in general agreement with Prof. Illing, although he might not go quite so far in criticism of the hypothesis of gravity separation. He did not wish to cross swords on this subject, but at the moment he was not prepared to treat the hypothesis quite so definitely as Prof. Illing had done.

He would suggest that secondary migration might be a longer and more varied process than had been indicated in the paper. Indeed, secondary migration might proceed in a number of stages. He knew of cases in which source rocks had been subjected to several different earth movements and each of these movements might have affected the migration of oil. Indeed, it was probable that in many cases the present disposition of oil in a field had been influenced by earth movements subsequent to the original formation of the oilpools.

A further point was the possibility in the later stages of secondary migration, of there being very great differences in the levels of an oilsand at the top of a dome and in the adjacent synclines. The difference in level of one and the same horizon at these opposite points might amount to many thousands of feet and one had to consider the resulting differences in pressure and temperature and their possible effects during the later stages of the secondary migration of petroleum.

Without very close study of the paper he would not attempt any more important contribution to the discussion, and he merely mentioned the above points to indicate the importance of a comprehensive survey of evidence.

Mr. L. Owen said that the Institution was to be congratulated on securing this paper, which would serve as a signpost to expermental and deductive lucidity for those who, in Prof. Illing's trite phrase, " think untidily."

With the author's conclusions he was, in the main, in agreement, but the paper was so full of grist that the speaker found it impossible to condense the comments he would have desired to make into anything like the time available.

He must, however, refer to the beautiful experiments on interfaces. To some, those experiments might appear rather artificial, but it should be remembered that the interface was an integral feature in every conceivable oilfield. Wherever there was a fault there was an interface and the behaviour of oil, water, and gas on either side of such interfaces could be studied in fields where the stratigraphical conditions were known fairly definitely.

The speaker's own experience fitted in remarkably well with Prof. Illing's conclusions, which dealt purely with the quantitative effects at the interface. There was, however, another aspect—a qualitative effect—which Prof. Illing apparently had not attacked, but which the speaker had been able to study in widely separated localities.

Usually, the passage of oil across an interface resulted in a differential loss of the heavy end, particularly of the asphaltic ingredients, and this fact made it possible to trace the direction and the course of migration. The distribution of oil and water, as indicated in Prof. Illing's experiments, would be of great value in giving an independent check on this direction and this knowledge would (and has been within the speaker's experience) a most useful guide for indicating where, and where not, to drill, particularly when searching for the " original " oil in a pool.

It might be noted, here, that it is probable that such substances as Manjak and Ozokerite represent the heavy end held up by differential filtration at the interface.

In one field, known to the speaker, the 150°–175° C. fraction accounted for 4·5 per cent. by weight, within narrow limits, of the crude oil of the main pool. In wells separated from the main pool by defined faults, the value of the 150°–175° C. fraction rose to 6 per cent. and even 10 per cent., and this filtered oil approximated to a pure paraffin base whereas, in the main pool, the crude was of mixed base.

Where the beds, on the fringe of the main pool and separated from it by faulting, had a definite dip away from the pool, the first

wells beyond the pool gave good production of oil. Travelling down dip, the gas-oil ratio increased until gas alone was struck, and, finally, salt water. This distribution is, of course, very different from what would be expected from the ordinary flotation theory, but agrees with the conception of interface filtration at the up-dip end of the stratum.

In one respect, Prof. Illing's experiments do not represent the conditions under which we may assume migration to occur, in so much as the beds employed are in a static condition. In nature, we may assume that migration occurred in the main, in beds which were in movement.

Under dynamic conditions, the so-called "impermeable" silts and clays would probably allow of the differential filtration of oil and water. Experiments in which the glass tubes were replaced by transparent celluloid capable of distortion would be likely to produce interesting results, particularly when working with low propulsive pressures.

It is probable that the pressure gradients in the short tubes used by Prof. Illing are much greater than those which actually occur in nature over corresponding distances.

Mr. J. C. Templeton subsequently wrote :—

The first query which comes to mind is, to what extent are the conditions assumed by Prof. Illing under which primary migration commenced bound up with the conditions governing the origin of oil ?

Considering the various theories of the origin of oil, i.e., organic, inorganic, cosmic, etc., which have a considerable following amongst the geological profession, one finds general unanimity in that the factors of great pressure and heat are considered essential. If these two factors are admitted, then it does seem vitally important that such factors, to whatever degree the individual investigator allocates to them, should be the foundation conditions under which primary migration commences; also, unless the particular investigator has reached certain conclusions in regard to the origin of oil and the conditions attendant thereon, either as a result of his own research or the research of others, it seems very possible that any theory of primary migration not based thereon may fall to the ground.

It would therefore be most interesting to know in regard to the origin of oil if Prof. Illing, as the result of his investigations, has come to certain conclusions in regard to the conditions prevailing at this stage, and if such conclusions are the foundation of his present theory of primary migration ?

Personally I have difficulty in conceiving that oil during primary migration through clays and other relative non-porous beds can pass through what are in effect filter beds without leaving the slightest traces of its passage. There are many instances obtained in the field where the tests of certain clays, shale and marls beds have indicated minute traces of petroleum, and where other similar beds in the same series and in same bore-holes have shown no traces whatsoever. Also, there are known instances where certain porous sandy beds containing oil are interspersed with clay, shale and other porous sandy beds, the latter completely dry, and none of them with the slightest indication of oil having passed through.

If primary migration can be as extensive as Prof. Illing indicates, how can he explain the fact of the migrating oil being selective, leaving traces in some non-porous beds and not in others? Furthermore, why should a cap rock stop migration? Surely the average cap rock is no more compact and no less porous than many of the clay and shale formations which one meets in the average oilfield section. If migration can be so complete as to pass through the very considerable thicknesses of relatively non-porous clays, shales, etc., which in many oilfields separate the assumed source rock from the reservoir rock, it is difficult to understand why in many instances migration did not continue to the surface, and be represented by extensive seepages.

I personally would like to see a complete picture, commencing with the conditions under which oil is formed, and thereafter using such conditions as a foundation for building up a theory of primary migration (vertical and lateral) comprehensive enough to embrace the average general conditions known to exist in the earth's crust in so far as they concern oilfields.

Prof. Illing, in reply, desired to thank the President and the members of the Institution for their kind reception of his paper. The subject was a very controversial one, and he did not wish to avoid criticism; in fact, he felt that any good that would accrue would be largely due to the keen discussion of different points of view, the elimination of the unsound ideas, and the selection of those features which fitted with the known facts.

Many of the speakers had stressed the point that primary migration was closely allied to the whole subject of oil origin. He admitted this; in fact, he had stressed it in the body of his paper. It was obviously absurd to suggest that oil migrated under the influence of compaction if at the same time one held that oil originated under high pressure and temperature at a later stage in the geological cycle. His own view had crystallised only

after a prolonged study of both oil origin and migration. Gradually the weight of evidence had forced him to believe that neither high temperature nor pressure could be called on as the governing cause of oil formation. From this position it was only a logical step to the theory that oil formation occurred in the sedimentary cycle. However, if they were to embark on a discussion of the origin of oil, it would leave little opportunity to deal with the subject in hand.

He would like to emphasise that in his paper compaction and lateral pressure were linked as two separate means of obtaining the same result, the squeezing of the strata. Also, compaction was a very long geological process. Not until many thousands of feet of sediments had been piled on top of the source rocks would the compaction become negligible. Oil might originate at any stage of this cycle, though the speaker felt that it was in the early stages rather than the later. It is true, as Mr. Beeby Thompson had remarked, that sediments of modern origin had failed to yield considerable quantities of oil; but were considerable quantities of oil necessary? A small percentage of oil in a large bulk of source rock would yield an oil-saturated reservoir rock by the process of oil concentration. He agreed that the erratic form of some oil impregnations and of the course of oil movement were sometimes very difficult to explain. The more cases we could get of accurate descriptions of the facts, the more data would be available to help us on the road of discovery. He would like to reiterate that all of the experimental work he had done had been undertaken to elucidate features observed in the field, and his case was not based on experiment alone.

It was very dangerous to assume that a shale or clay contained no trace of oil without careful laboratory tests. As a matter of fact, many shales neither smelt of oil nor did they appear to contain oil, but could be proved by tests with solvents to contain small quantities. For this reason, he would not like to say whether oil could migrate through a clay mass without leaving a trace of its passage, and the field examples of supposed cases would require very careful examination.

Mr. Beeby Thompson had asked what kinds of oil he had used in his experiments. Crude oil from Pennsylvania, Venezuela, Persia and Mexico had at different times been employed, also refined products such as kerosine and light spindle oils. The types of result obtained at the coarse-fine interface were similar in all cases, the quantitative factors (i.e., the back pressure involved) no doubt in each case were a function of the oil. In nature, as the overburden increases and the temperature rises, the viscosity

of the oils would diminish, and the surface tension of the oil and water would approach each other. These factors would alter the quantitative data, but would not affect the qualitative results.

Mr Romanes had made a very interesting suggestion with regard to the quantity of residual oil in the source rocks in folded and unfolded regions. He was unaware of any data on this point, but would like to carry the suggestion a stage further by a quantitative examination of residual oil in a vertical sequence as well as a lateral sequence. There were, unfortunately, serious difficulties in any such study, because the rocks themselves were difficult to duplicate, and the residual pore-space was undoubtedly a function of the silt-sand aggregate in the clay rock. Variations in this would affect the results. At the same time he would like to point out that in the heart of the Pennsylvanian geosyncline it was very questionable whether any serious lateral pressure had occurred at all. The oil in this part must have been segregated by forces other than lateral pressure, and in this case simple compaction seemed the dominant influence.

Mr. Romanes found difficulty in accounting for the enormous gas pressures if oil was formed at an early stage, but surely these pressures were built up exceedingly slowly as the weight of overburden increased and were a faithful reflection of this pressure so long as the sediment was compacting. Agreeing that compaction did not cease until many thousands of feet of sediment had been formed, we have sufficient force to account for all the pressures found in nature.

The speaker was very glad indeed to hear Mr. Romanes stress the view that there were several primary oil horizons in the Jurassic and Cretaceous, and he agreed completely with this re-emphasis of the earlier views held before the discovery in Thuringia.

He was very reluctant to enter into a discussion with Mr. Cunningham Craig, because it was obvious that it would lead them nowhere. There was hardly a single statement which the latter had made with which he did not find himself in complete disagreement. Mr. Cunningham Craig evidently did not believe in experiments as an aid to geologists, and apparently he and the speaker could not meet on the common ground of field experience, for in the past they had always obtained divergent conclusions from the same field data. Mr. Cunningham Craig had raised the hoary argument that the time factor upset all the conclusions from experimental evidence, to which the speaker would rejoin that all the infinity of time to which geologists turned in their distress would not make the impossible possible. A reaction either could

or could not take place under certain conditions. Time, even geological time, was not a governing condition.

He did not agree with Mr. Cunningham Craig's contention that oil was formed deep down in the earth's crust, where there was probably very little water. His assertion that "they knew that oil was formed under very high pressure, obviously long after the rocks had been compacted" was a wholly one-sided and incomplete picture. The speaker, for one, was prepared to challenge this assertion and could point to abundant evidence and a wide literature in support of that challenge. Again, Mr. Cunningham Craig apparently had little doubts or difficulties about accepting migration through thousands of feet of rocks slightly affected by water saturation. To the speaker such conditions were astonishing in oilfield strata. Surely water saturation was the normal feature and a partly dried rock was abnormal, though it sometimes occurred.

Mr. Cunningham Craig complained that due attention had not been given to the phenomenon of gas drive and then went on to explain that gas was never present as free gas but only as potential gas, being present as a liquid. If it were present only as a liquid, then in what way could its activities differ from that of a simple oil under pressure unless the gas were allowed to vaporise. Surely gas would be present as free gas, as condensed liquid or as gas in solution, depending on the type of hydrocarbon, the quantities of oil and gas and the pressure-temperature conditions. The speaker would certainly not negative the activity of gas drive in the way that Mr. Cunningham Craig suggested, and in the paper he had given far greater scope to this activity.

He was glad indeed to agree with Mr. Cunningham Craig on two points. Firstly, that all oil was not formed in argillaceous rocks (and here again he might read the paper with more care), and secondly that nothing he had said was very new. If by new Mr. Cunningham Craig meant novel, the speaker had no intention of competing with him by suggestions comparable with the latest of Mr. Cunningham Craig's dicta, that all oil migration was by means of films. When a shred of evidence could be produced in support of this extraordinary assumption it would be time enough to inspect it with more care.

The speaker was very glad indeed that Dr. Wade had mentioned the suggestive work of Versluys. The views of the latter were now fortunately becoming available, and he had read them with great interest. He agreed, too, with Dr. Wade that all oil is not formed in argillaceous rocks. In the paper he had referred to them as such merely as a convenient lithological description of a source

rock, but he did not wish to imply that all source rocks were necessarily clays. With regard to the inclined water table, the speaker could not agree that a case such as that of Cushing, could be explained away by variations in texture, etc.; the relation to structure was too consistent for that.

There was no doubt a wide field for co-operation between the geologist and the chemist, and if the two would get together and produce accurate records of field data the results would be invaluable in studying oil migration.

Mr. Dewhurst had laid his finger on what he agreed was the weak spot in the paper. He had made the process of secondary migration appear shorter than primary migration, as though it were but an adjunct of the latter. The reasons were twofold. Firstly, he wished to emphasise particularly the first process, because so many writers had ignored it, and secondly he had in mind the preparation of a second paper on accumulation which would automatically involve a more complete study of the results of secondary migration. For this reason he had given little more than a summary of the main principles of secondary migration.

To Mr. Owen he was particularly indebted for his interesting contribution to the discussion. As he had said, the essence of the speaker's theory was the emphasis of the filtration at the coarse-fine interface. In nature these pressure differences are always small, though it is difficult to conceive that this is the case when dealing with an open sand on the one hand and a clay on the other. He had not gone deeply into the question of changes in oils during migration, but was fully aware that this was a side which deserved careful study. There is a considerable literature on the subject in its chemical aspects, but geologists have not applied this to their own problems to any extent.

Mr. James Templeton had raised the question of the obvious necessity for an agreement between the theory of oil origin and migration. To this he had replied at an earlier stage. He must reiterate, however, that there is a very considerable body of geological opinion, and has been for the last two decades, which disagrees with the older view that oil originates under pressure and at high temperature. Mr. Templeton is under a misapprehension, for there is no general unanimity on the subject of the governing conditions for oil formation. His own view was that oil originated early, and one of his main reasons for thinking so had been put by Mr. Templeton himself in the difficulty he raised about the cap rock stopping migration when other apparently similar rocks allow oil to pass. This apparently contradictory behaviour is irreconcilable so long as we regard the rocks

as they are at present. The process only becomes intelligible when we visualise the finer strata as gradually squeezing and becoming compact. Secondly, we must view the fluid movements as passing through all the rocks, the water passing onwards, while the oil is held back in the coarse. Mr. Templeton's queries gave the speaker the opportunity to reiterate that he did not believe that these fine compacting sediments are impervious to oil. The essence of his theory was the holding back of the oil at the coarse-fine interface unless or until there is a sufficient difference in pressure at the interface to burst the barrier. Then oil would pass. He did not think that most of the migrating oil passed through the relatively non-porous clays, its passage would be blocked by such rocks; but before these rocks become non-porous and while they were compacting sediments, it was quite another matter. There was no difficulty in understanding why migration might fill a reservoir rock, but the same migration will not necessarily continue to the surface and be represented by extensive seepages. Compaction was only commencing in the uppermost layers of the sediment, and in this zone the oil is merely entangled in the clay-water mixture, the gradual expression of oil does not begin, according to experiments on compaction, until the volume of the sediment has been considerably reduced.

The proceedings terminated with a hearty vote of thanks to Prof. Illing.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

ANNUAL REPORT OF THE COUNCIL, 1932.

THE Annual Report and Accounts for the year ended December 31st, 1932, are hereby submitted.

The following table shows the alterations in membership during the year 1932 and the total membership at December 31st, from which it will be seen that unfortunately there has been a slight decrease in numbers :—

	TOTAL 31.12.31.	CHANGES DURING 1932.							TOTAL 31.12.32.
		New.	Transferred to.	Resigned.	Deceased.	Removed.	Transferred from.	+ —	
Honorary Members ..	13	5	1	—	1	—	—	+ 5	18
Members	568	34	8	18	4	14	1	+ 5	573
Associate Members ..	475	20	13	21	—	19	8	—15	460
Students	129	14	—	6	1	7	15	—15	114
Associates	94	6	2	3	—	10	—	— 5	89
TOTALS	1279	79	24	48	6	50	24	—25	1254

In addition to the above on December 31st, 1932, 5 Members 11 Associate Members, 2 Students and 2 Associates had been elected but had not taken up their membership, and 31 Candidates were awaiting election.

The Council regret to have to announce the death of the following Members: H. Barringer (Past President), Dr. Van H. Manning (Hon. Member), H. E. Bradshaw, Dr. Sidney Powers, and J. L. Rossini (Members) and G. Paice (Student).

The Accounts for the year ending and Balance Sheet as at December 31st, 1932, are presented.

The Council considers the position shown as satisfactory, having regard to the difficult conditions encountered during 1932.

The Scholarships awarded by the Institution at the Royal School of Mines and at Birmingham University have been provided for in the Accounts, and it has been decided to continue the awards in 1933.

The Committee for the Standardization of Methods of Testing Petroleum and its Products has continued to hold its meetings. The Committee dealing with the Measurement of Oil in Bulk has issued the first volume of their publication on the subject. An Engineering Standardization Committee has been appointed during the year.

The Institution has been represented on the following: British Standards Institution, the American Society for Testing Materials, the Advisory Board of the Department of Oil Engineering and Refining of the University of Birmingham, the Imperial Mineral Resources Bureau, the British Committee of the World Power Conference, the Mechanical Warfare Board of the War Office, the Ramsay Memorial Laboratory Advisory Committee, the Empire Mining and Metallurgical Congress and the Manchester Cancer Research Committee.

Eight General Meetings and one Special Meeting of the Institution were held during the year 1932, at which the following papers were read:—

One Hundred and Fortieth General Meeting, January 12th: "The Chemistry of the Conversion of Algæ into Bitumen and Petroleum and of the Fucosite-Petroleum Cycle," by J. E. Hackford.

One Hundred and Forty-first General Meeting, February 9th: "Displacement Pumping as Applied to Oil Wells," by Albert Millar.

Nineteenth Annual General Meeting, March 8th: Presidential Address.

One Hundred and Forty-second General Meeting, April 12th: "Symposium on Spontaneous Ignition Temperatures," by L. J. Le Mesurier, J. L. Chaloner and F. A. Foord.

One Hundred and Forty-third General Meeting, May 10th: "Modern Oil Production Problems," by A. Beeby Thompson, O.B.E.

Special Meeting, June 14th: at which apparatus connected with the Industry was shown and various short papers relating to same were read.

One Hundred and Forty-fourth General Meeting, October 11th: "Some Observations on the Study of an Oilfield," by J. W. Weil.

One Hundred and Forty-fifth General Meeting, November 8th: "The Mechanism of Lubrication," by W. F. Parish and L. Cammen, read by Dr. F. H. Garner.

One Hundred and Forty-sixth General Meeting, December 13th: "New Methods of Dewaxing and Acid Refining Mineral Oils," by Nils Backlund.

The Meetings continue to be held at the House of the Royal Society of Arts and the Council beg to tender their thanks to that Society for their courtesy.

Joint Meetings have been held in 1932 with the Institution of Automobile Engineers on March 1st and the Institute of Fuel on May 17th.

Vol. XVIII. of the Journal was published in twelve parts and contained the papers read at the General Meetings, together with a number of specially contributed articles. The Abstract Section continues to be a very satisfactory part of the Journal, and over 1,300 Articles and Patent Specifications were dealt with during the year under review.

The Council have altered the conditions of the Award of the "Redwood Medal," and decided to confer the Medal on Petroleum Technologists of outstanding eminence irrespective of Nationality and Membership of the Institution. The Award for 1932 was made to Dr. L. Edeleanu, and the Medal was presented at a Special Meeting held at the Royal Institution on Friday, October 7th, 1932, when Dr. Edeleanu gave an address on the History of the Process associated with his name.

The Council note with pleasure the growing interest displayed in the Students' Section.

Six papers were submitted for the Students' Medal and Prize. The Medal and Prize were awarded to Mr. A. Evans, of the Royal School of Mines, for his paper, "The Physical Properties of Mixtures of Bitumen with Finely Divided Mineral Matter." Mr. M. E. Kelly, of Birmingham University, was highly commended for his paper, "The Origin and Environment of Petroleum Source Sediments."

The Institution's Scholarships for 1932-33 were awarded to Mr. W. G. Gillingham, of the Royal School of Mines, and Mr. A. B. Cameron, of Birmingham University.

Mr. Thomas Dewhurst, A.R.C.S., F.G.S., has been elected President of the Institution. Mr. Alexander Duckham and Mr. Arthur W. Eastlake have been re-elected, and Mr. Ashley Carter, Mr. C. Dalley, Mr. J. McConnell Sanders and Dr. F. B. Thole have been elected Vice-Presidents.

The Council is pleased to note that the Branches in Persia, Rumania, South Wales and Trinidad continue in active progress and render definite assistance to the Parent Institution in many ways.

The Library Committee report that the usefulness of the Library has continued to be evidenced by the number of calls made upon it. Arrangements have been made whereby members are permitted to borrow books, and the Rules were published in the October issue of the Journal. From the number of books issued on loan, it is obvious that this feature is appreciated.

The Council desire to state that, while every effort is made to ensure that the most important works on petroleum technology are included in the Library, they would, nevertheless, welcome suggestions from members as to books which could, with advantage, be obtained.

The Council have approved the following alteration to the By-Laws: Substitution of the following for "Form A" (Application Form for Membership) in the Appendix to the By-Laws:

Form A

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

Name in full.....
(IN BLOCK LETTERS)
Place of birth.....

Date of birth..... *Nationality*.....

Professional designation.....

Address .....

.....

I, having known the Candidate personally for.....years, propose and recommend him in accordance with the By-Laws as set out herewith as a fit and proper person to belong to the Institution.

Signature .....

Address .....

Date..... .....

I, having known the Candidate personally for.....years, second the proposal and recommend him in accordance with the By-Laws as set out herewith as a fit and proper person to belong to the Institution.

Signature .....

Address .....

Date..... .....

Signatures and addresses of two Members or Associate Members supporting the application. (*If these know the Candidate personally they should state the fact.*)

.....

.....

.....

.....

NOTE.—The form must be completed as regards the requisite number of Proposer, Seconder and Supporters, who must be either Members or Associate Members.

ENGAGEMENT

I, the undersigned, do hereby agree that, in the event of my election as Member, Associate Member, Student, or Associate, I will be governed by the regulations of the Institution of Petroleum Technologists as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the meetings thereof as often as I conveniently can; provided that whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Signature of Candidate.....

Date.....

NOTE.—The above form when completed should be forwarded to "The Secretary, The Institution of Petroleum Technologists, Aldine House, Bedford Street, Strand, London, W.C.2."

The Benevolent Fund of the Institution has been administered by a Special Committee since its establishment in 1929 at the instance, and during the Presidency of, Dr. A. E. Dunstan.

Although up to the present time the applications for assistance received and dealt with by the Committee have, happily, been few in number and adequately satisfied, the Fund has not attained large proportions.

The Council are again earnestly commending to the generosity of Members the needs of this Fund, which has, so far, been contributed to principally by the benevolence of deceased Members in the shape of Bequests and Legacies.

The Council desire to appeal to Members actively to support the Fund by making annual contributions, even though small, so as to enable it fully to realise the worthy objects for which it exists.

The Fourteenth Annual Dinner was held on October 7th, 1932, at the Connaught Rooms, Great Queen Street, London.

The Council beg to tender their thanks to the following for their services rendered to the Institution: Lord Plender, G.B.E., Honorary Treasurer; Messrs. Ashurst, Morris, Crisp & Co., Honorary Solicitors; Messrs. Price, Waterhouse and Co., Auditors.

The Auditors retire and, being eligible, offer themselves for re-election.

By Order of the Council,

ARTHUR W. EASTLAKE,

Honorary Secretary.

Dr. REVENUE ACCOUNT FOR THE YEAR

	£	s.	d.
To Salaries	985	18	1
„ Rent, Rates, etc.	441	19	0
„ Printing and Stationery	184	9	3
„ Postage	257	7	9
„ Expenses of Meetings, Including Hire of Hall	192	1	4
„ Journals and Publications (Net Expenses)	844	10	6
„ Grants to Branches	78	0	0
„ Sundry Expenses	285	15	0
„ Students' Prize and Scholarship Fund	80	0	0
„ Depreciation of Office and Library Furniture and Library Books	54	2	5
„ Library Expenditure :— Purchase of books and journals, etc.	57	2	2
„ Students' Section	23	3	4
„ Auditors' Fee	10	10	0
	£3494	18	10

STUDENTS' PRIZE AND

1932.		£	s.	d.
Dec. 31.	To Scholarships Granted	80	0	0
	„ Balance Carried Forward	5	0	0
		£85	0	0

RESEARCH FUNI

1932.		£	s.	d.
Dec. 31.	To Grants for Research	60	15	0
	„ Balance Carried Forward	496	7	3
		£557	2	3

YEAR ENDED 31ST DECEMBER, 1932. Cr.

	£ s. d.	£ s. d.
By SUBSCRIPTIONS :—		
Members	3030 7 0	
Special	20 0 0	
		3050 7 0
„ INTEREST AND DIVIDENDS LESS TAX		181 18 4
„ BALANCE, BEING EXCESS OF EXPENDITURE OVER INCOME FOR THE YEAR CARRIED TO BALANCE SHEET		262 13 6
		£3494 18 10

SCHOLARSHIP FUND.

1932.		£ s. d.
Jan. 1.	By BALANCE BROUGHT FORWARD	5 0 0
	„ REVENUE ACCOUNT	80 0 0
		£85 0 0

FUND.

1932.		£ s. d.
Jan. 1.	By BALANCE BROUGHT FORWARD	541 5 9
	„ INTEREST AND DIVIDENDS LESS TAX	15 16 6
		£557 2 3

BALANCE SHEET AS

	£ s. d.	£ s. d.	£ s. d.
CAPITAL OF THE INSTITUTION, under Bye-Law Section 6, paragraphs 14 and 15 :—			
Life Membership Fund—			
As at 31st December, 1930	519 0 0		
Additions during year 1932	47 5 0		
		566 5 0	
Entrance Fees—			
As at 31st December, 1931	2106 5 0		
Additions during year	120 15 0		
		2227 0 0	
Profit on Sale of Investments—			
As at 31st December, 1928	2 10 0		
Add : Profit during 1932	12 6		
		3 2 6	
Donations—			
As at 31st December, 1928		326 5 0	
			3122 12 6
STUDENTS' PRIZE AND SCHOLARSHIP FUND ..			5 0 0
RESEARCH FUND			496 7 3
MEMBERS' SUBSCRIPTIONS PAID IN ADVANCE			129 6 0
JOURNAL SUBSCRIPTIONS PAID IN ADVANCE			454 11 9
SUNDRY CREDITORS :—			
General Account		281 6 11	
Research Fund		6 5 0	
			287 11 11
REVENUE ACCOUNT :—			
Balance as at 31st December, 1931 ..		1200 8 8	
Less : Subscriptions, 1931, now written off		52 4 6	
		1148 4 2	
Add : Subscriptions previously written off now recovered		32 11 0	
		1180 15 2	
Less : Deficit for year as per separate Account		262 13 6	
			918 1 8
			£5,413 11 1

Members of Council { J. KEWLEY. ALFRED C. ADAMS.

AUDITORS

To the Members of

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

We have examined the above Balance Sheet with the books of the Institution are of opinion that such Balance Sheet is properly drawn up so as to exhibit a true according to the best of our information and the explanations given to us and as

3, FREDERICK'S PLACE,
OLD JEWRY, LONDON, E.C. 2.
1st February, 1933.

AT 31ST DECEMBER, 1932.

	£	s.	d.	£	s.	d.
INVESTMENTS AT COST :—						
On Account of Capital :—						
£1250 0 0 3½% War Loan	1196	18	6			
650 0 0 3½% Conversion Loan	505	7	0			
664 6 6 London County 3% Consolidated Stock	481	10	6			
150 0 0 Birmingham Corporation 6% Stock 1936/46	146	16	0			
100 0 0 Wigan Corporation 5% Redeemable Stock	99	14	11			
100 0 0 5% Conversion Stock 1944/64	102	3	6			
150 0 0 Wandsworth District Gas Co. 5% Debentures	154	8	6			
400 0 0 Metropolitan Water Board	346	10	7			
				3033	9	6
(Market Value at 31st December, 1932, £3,325.)						
On Account of Revenue :—						
800 0 0 3½% War Loan	810	15	9			
On Account of Research Fund :—						
350 0 0 3½% War Loan	358	16	9			
				1169	12	6
(Market Value at 31st December, 1932, £1139.)						
OFFICE AND LIBRARY FURNITURE (excluding Presentations) :—						
As at 31st December, 1931	424	10	4			
Additions during year	18	11	9			
	443	2	1			
Less : Depreciation	21	4	6			
				421	17	7
LIBRARY BOOKS (excluding Presentations) :—						
As at 31st December, 1931	131	11	7			
Less : Depreciation at 25%	32	17	11			
				98	13	8
MEMBERS' SUBSCRIPTIONS OUTSTANDING :—						
Estimated to produce				108	7	3
				4832	0	6
SUNDRY DEBTORS AND PAYMENTS IN ADVANCE ..				75	14	2
CASH ON DEPOSIT WITH BANKS :—						
Research Fund				143	15	6
CASH AT BANK AND IN HAND				362	0	11
				£5413	11	1

REPORT.

and have obtained all the information and explanations we have required. We and correct view of the state of the Institution's affairs at 31st December, 1932, shown by the books of the Institution.

PRICE, WATERHOUSE & CO.

BENEVOLENT FUND.

	£ s. d.	£ s. d.
Balance at Bank on Current and Deposit Account, 1st January, 1932		414 2 8
Donations	516 13 0	
Subscriptions	18 0 0	
		534 13 0
Interest on Deposit Accounts		23 16 0
		£972 11 8

	£ s. d.
Grants in Aid	73 17 4
Balance at Bank on Current and Deposit Accounts, 31st December, 1932	898 14 4
	£972 11 8

We have examined the above Account with the books and vouchers of the Fund and find the same to be correct.

PRICE, WATERHOUSE & CO.

3, Frederick's Place,
Old Jewry, London, E.C. 2.
1st *February*, 1933.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE TWENTIETH ANNUAL GENERAL MEETING of the Institution was held at the House of the Royal Society of Arts, John Street, Adelphi, London, W.C. 2, on Tuesday, March 14th, 1933.

Mr. JAMES KEWLEY, President, in the Chair.

The Secretary read the Notice convening the Meeting and the Auditors' Certificate.

Minutes.

The Secretary read the Minutes of the last Annual General Meeting, which were confirmed and signed,

The President stating that the questions which had been raised by Dr. W. R. Ormandy and Mr. C. Dabell at the last Annual General Meeting had both been answered.

Result of Ballot for Council.

The Secretary announced that there had been five nominations for Council—four for re-election and one new nomination. The candidates were Mr. G. H. Coxon, Dr. F. H. Garner, Mr. J. S. Jackson, and Dr. A. Wade for re-election, and Mr. E. A. Evans for election. The ballot had resulted in the re-election of Mr. G. H. Coxon, Dr. F. H. Garner, Mr. J. S. Jackson and Dr. A. Wade.

New Members.

The President proposed that the list of Honorary Members, Members, Associate Members, Students and Associates elected and transferred during 1932 should be laid on the table, and this was agreed to.

The Secretary read the following list of members elected since the last General Meeting, and also the list of nominations :—

As Members.—Harry Chetwin, Frederick William Scott King, Charles Craven Sanders, Arthur Norman Wigner.

As Transfer to Member.—Thomas William Starkey Robinson.

As Associate Members.—Jacques Maurice Emile Ballet, H. A. Blackmore, E. D. R. Fraser, Paul I. Trofimoff.

As Transfer to Associate Members.—Douglas Henry Carter, William Jan Hessels.

As Student.—Roderick Æneas Chisholm.

As Associates.—Albert Elisee Garand, Edward George Grant.

Annual Report of Council, 1932.

The President remarked that before formally moving the adoption of the Annual Report of Council he desired to supplement it by a few remarks.

He regretted to find that the optimism which he had expressed at the Dinner last year had not been really justified. The membership had suffered a slight decrease. It was, however, not very large, taking into consideration the bad times. That in itself was

somewhat unfortunate, but it was rather more unfortunate that one of the marked decreases in membership was in the Student Section. That was not due to any lack of interest or activity on the part of the students, as no less than 50 per cent. of the papers which had been read at the Students' Meetings had been read by the students themselves. Nevertheless, as the students formed the Institution's future potential Members he thought the Students' Section well merited the attention of the senior Members of the Institution who, by a little personal attention, could do a great deal to help it along. They were particularly grateful to Mr. Ashley Carter for the great interest he had taken in the Students' Section during the last year.

With regard to the membership, the Institution had members at the moment in no less than 37 foreign countries and in 11 Colonies and Dominions; its international character was well emphasised, and surely rendered it very well fitted for the organizing of a World Petroleum Congress.

Among those lost to the Institution by death he must particularly mention Mr. Herbert Barringer. Unfortunately ill-health for two or three years had prevented Mr. Barringer taking that very active part in the functions of the Institution which had been his wont.

The work of the Standardization Committee with its numerous branches was steadily progressing under the careful guidance of Prof. J. S. S. Brame. It was going to have a great opportunity of giving a lead this year in the matter of international co-operation at the forthcoming Congress. Personally he felt very strongly that if they could succeed in reaching international agreement on that one point only, the holding of the Congress would really have been justified. The first step was very often the most difficult.

With regard to the meetings, for the first time a meeting had been held in June, although he regretted to say that, by a decision of the Council that day, there would not be a meeting this June, owing to the World Petroleum Congress. Personally he saw no reason why the Institution should æstivate during the period in which most of its members were likely to make most use of it—namely, when they were home on leave, and he looked forward to the time when the Institution would hold meetings in all months, except possibly August.

The Journal spoke for itself. Its merits were generally recognized all over the world. Its circulation could truly be said to be world-wide. It was a living testimony to the activities of Dr. A. E. Dunstan, Mr. George Sell, Mr. W. H. Thomas, and the active band of Abstractors.

The other points in the Report required, he thought, little amplification. He might commend again to the attention of members the Benevolent Fund. It was true that, fortunately, there had not been many claims on the Fund; the amount available had been sufficient to meet immediate needs; but he thought it was their duty to build up a Fund of dimensions more in keeping with the dignity of the Institution. If every Member were to add only 2s. or 3s. a year to his annual subscription it would be of very considerable assistance in the building up of so eminently desirable a Fund.

He proposed the adoption of the Report, excluding the Accounts and Balance-Sheet, which would be taken separately, and he would ask Mr. Dewhurst to second the motion.

Mr. T. Dewhurst, in seconding the motion, said in view of the general economic conditions which had prevailed during the year the Annual Report disclosed a healthy and gratifying state of affairs. There was nothing that he could usefully add to the President's remarks in amplification of the Report, and he, therefore, formally seconded the proposal that it be approved and adopted.

The motion was carried unanimously.

Balance-Sheet and Accounts for 1932.

The President remarked that the expenditure this year had exceeded the revenue, but he did not regard that as a fact of very great importance. It was not the first occasion on which that had happened in the history of the Institution. The balance-sheet showed that the position was sound.

Before proposing the adoption of the Accounts he desired to pay particular tribute on the present occasion to the work of Mr. Alfred C. Adams who, through the whole lifetime of the Institution, had presided so ably over the Finance Committee, and who now retired from that office. The Finance Committee particularly was one of those Committees which depended largely on its Chairman, as so much of the work was done behind the stage. The Institution had been, indeed, fortunate in having Mr. Adams as its adviser for so long. He was about to shed his mantle on Mr. C. Dalley, and he (the President) ventured to say that that gentleman showed signs of being able to wear that mantle gracefully and efficiently.

He had great pleasure in proposing the adoption of the balance-sheet and accounts, and in asking Mr. Adams, in seconding the motion, to give his usual lucid explanation.

Mr. Alfred C. Adams said that for many years it had been an annual treat offered to him by the President to second the motion for the adoption of the Balance-Sheet and Accounts of the

Institution. In doing so on the present occasion he would like to say a few words in explanation of some of the items, and, in particular, as to how it had come about that there was an adverse balance. It was not a very usual thing for the Council to come before the members with an adverse balance, but in an Institution of the kind of their own—which, after all, did not exist for profit—it was not easy always exactly to make the expenditure fall within the scope and limit of the revenue. It could not, after all, like a business did, make very energetic efforts to try to increase the turnover. It was dependent upon its subscription revenue ; but he would refer to that later on.

He supposed that most people, when they took up accounts for the first time, immediately looked to see on which side the balance was ; and possibly a good many of the members had looked at the printed accounts to try to find out what it all meant.

Although there was shown an adverse balance of £262 on the year's working, it could very readily be seen just what had happened. Looking at the Revenue Account, and taking the item of "Journals and Publications," it would be seen that this year the figure was £844 10s. 6d. as against £505 for the year 1931, which was an increase of practically £340. In order partly to explain why that item had gone up he might mention that the Council had, during the year, published a good deal more material in the Journals, amounting to not very far short of 200 pages. Expressing that in another way, it meant that the Institution had published 13 Journals in the year, because the extra 200 pages really represented an extra Journal. That, of course, had cost money.

Again, normally the Institution enjoyed a considerable revenue from sales of Journals and advertisements, but unfortunately in 1932 the revenue from the sales of Journals and advertisements had dropped £200 as compared with 1931. He wanted the members to keep in their minds that the adverse balance was only £262.

Then there was another item of Library Expenditure. That represented the purchase of books, journals, and various things for the Library during the year, amounting to £57 2s. 2d. That was an item which appeared in the Accounts for the first time, because the Council had decided (and he thought they had been wise in so doing) that that item should be reckoned as a revenue charge and should be dealt with in the year in which it occurred. So that the members would see that he had got £57 more towards his £262. But that was not quite the end of it, because it would be seen that in the present Accounts (he thought for the first time in the history of the Institution) there was shown a lesser revenue from subscriptions than in earlier years. There was £50 less of subscriptions to come into the Accounts of the year. Owing to

the depressing circumstances which all felt, not only in their businesses, but in their private lives, it was a little difficult, perhaps, to keep up the payments of subscriptions. He found that in many walks of life people were looking round to see where they could cut down subscriptions. He did not mean to say that the Institution members were trying to cut down their subscriptions, but some of them found a little difficulty in paying them at the due date. Therefore it had been found that quite an imposing amount of subscriptions had not come in when the books had had to be closed in order to produce the year's Accounts. Many of those subscriptions, he was sure, would come in; in fact, many subscriptions which had been written off had since been recovered, amounting to £32. So that although the Institution was down on subscriptions for the year, it did not mean that those subscriptions would not come in. It was hoped that they would be recovered and, if so, that would be all to the good in another year.

Taking the Accounts all through, the Council had been able to make quite a number of important economies in other items, which had brought the ultimate adverse balance down to £262.

He did not think the Student Prize or the Research Fund required any particular mention.

The Scholarships granted by the Institution amounted to £80, and that amount was paid out. There was a £5 balance which came forward every year. That had not been used for quite a long time.

With regard to the Research Fund, grants had been made for research during the year amounting to £60 15s. There was still a sum in hand to be dealt with, as the Council should decide, of £496 7s. 3d.

Turning to the Balance-Sheet, it would be seen that the investments on the credit side very nearly balanced the capital of the Institution, which was the corresponding entry on the debit side. There had been some £80 or £90 over, but that had since been invested; and in fact rather more had been invested, because there had been some further investment moneys.

At the present time he thought he might say that the money invested to all intents and purposes equalled the capital of the Institution. There was still an amount invested on account of revenue which was spendable money if it was found necessary to draw upon it for the requirements of the Council, and there was also invested on account of the Research Fund £358 16s. 9d.

It would be seen, as far as the Research Fund was concerned, that there was an amount on the debit side which represented the sum which had to be accounted for—£496 7s. 3d., and if the £358 16s. 9d., which was invested, and the £143 15s. 6d. lower

down, were taken and added together, and the £6 5s. which would be seen in the middle of the debit side was deducted, the sum of £496 7s. 3d. was arrived at. He was only saying that, as somebody might wonder why the two figures did not agree more readily.

Office and library furniture had been depreciated, as usual, and stood at £421 17s. 7d. The library books, which were exclusive of presentations, had been depreciated 25 per cent. and now stood at £98 13s. 8d. instead of as last year £131 11s. 7d. Members' subscriptions outstanding were estimated to produce £108 7s. 3d. As he had stated last year, it had been the custom for two or three years past not to take any notice of subscriptions owing which related to the year before, or to the years before the accounting year under review. Therefore members' subscriptions outstanding represented 50 per cent. of 1932 subscriptions, but not of any of the years before.

Cash at the Bank and in hand stood at £362 0s. 11d.

The net result on the balance-sheet was a balance on revenue account of £918 1s. 8d. of unspent money, which was available to the Council if they wished to spend more money. As he had said before, it was not possible to work the administration of an Institution like their own and always be quite sure that one was within the limit and scope of the subscription revenue of a particular year. Therefore the members must not be surprised if sometimes they got a balance in hand—a credit, and if sometimes they got an adverse balance—a debit.

With those remarks he formally seconded the proposition of the President that the Accounts be accepted.

Before sitting down, however, he did desire to refer to the Benevolent Fund. He would ask the members seriously to read what was said in the Report about that Fund. The remarks were very short, but they were very instructive. Particularly he wanted to draw members' attention to the fact that in commending the Benevolent Fund to the generosity of the members the Report said that it had so far been contributed to principally by the benevolence of deceased members in the shape of bequests and legacies. There were 1254 members in the Institution, and he did not think he was disclosing anything which he should not if he stated that the supporters of the Fund, other than deceased members who had bequeathed legacies, did not number the odd 54. The fund was a very worthy object. He happened to be the Chairman of the Benevolent Fund Committee, and he would like to see the fund going a little better, because it seemed to him that an Institution with such a large membership ought to be able to build up something which he was sure in time to come would be wanted, and it was only if the subject was kept in their minds

that they would achieve the object which they had set out to achieve. With those few words he left the matter with the members.

The motion for the adoption of the Balance-Sheet and Accounts was then put and carried unanimously.

The President enquired if any member had any question to raise with regard to the working of the Institution?

If not, he would ask the Secretary to read the Annual Reports of the Students' Sections.

Annual Reports of Students' Sections.

The Secretary read the Annual Reports of the Students' Sections for the year 1932, as follows:—

London Branch.—On December 31, 1932, the Student Members of the Institution numbered 114. There were in the London area four new Members, three Members transferred to other classes, six Members removed and resigned, and we regret to say one Member died. This reduces the already slender number of Students able to attend London Meetings to about 35 at the most. This fact causes the Committee some anxiety. At the Ninth Annual General Meeting, held in March, 1932, the following were elected to serve on the Committee:—

Mr. L. G. M. Roberts, Mr. P. Spens, Mr. G. Richardson, Mr. C. S. Lee, and Mr. N. C. Fraser.

Mr. Roberts was subsequently elected Chairman, and Mr. Fraser Honorary Secretary. During the year Mr. Spens resigned and Mr. W. J. Gillingham was elected in his place.

Seven Meetings were held during 1932, at which the following events took place:—

January, 1932 ..	Papers read by Mr. L. G. M. Roberts (Student), "Modern Fuel Criteria and Economics."
February, 1932..	Joint Meeting with the Graduates of the Institution of Automobile Engineers, when a Paper was read by Mr. K. Arter on "Fuel."
March, 1932 ..	Ninth Annual General Meeting.
October, 1932 ..	Paper read by Mr. T. R. H. Garrett, M.A., F.G.S. (Member), on "Varfull Draganeasa"—an Oilfield in Rumania.
November, 1932	Paper read by Dr. D. A. Howes, D.Sc. (Associate-Member), on the "Use of Synthetic Methanol as a Motor Fuel."
November, 1932	Joint Meeting held with the Students of the Institute of Fuel, when a Paper was read by Mr. L. G. M. Roberts (Student) on "The Problem of Fuel in Great Britain."
December, 1932..	Paper read by Mr. J. G. Withers, B.Sc. (Student), on "Fuel in Relation to High Speed Diesel Engines."

One excursion was made, and that was to London & Thames Haven Oil Wharves at Thames Haven.

Two Papers were entered for the Student's Medal and Prize from the London Section, and the Committee would like to congratulate Mr. A. Evans of the Royal School of Mines, who won the prize with his Paper on "The Physical Properties of Mixtures of Bitumen with Finely Divided Mineral

Matter." The Royal School of Mines Scholarship was awarded to Mr. W. J. Gillingham.

The attendance this year has continued to increase, especially amongst the Students. The Committee would, however, like to hear a little more discussion and points raised from the Students, as the onus is too frequently put on those senior Members whom we are always very pleased to see and welcome.

This year the Committee have started to send out a précis of each Paper to Members, and it is hoped that this was found to be of use.

The Committee would like to draw Members' attention to the fact that books can now be borrowed from the Library, and that Students can obtain tickets for the Institution's Annual Dinner at a reduced rate.

The attention of Members is also drawn to the opportunity afforded by the Annual Dinner held by the Branch to make the more intimate acquaintance of other Student Members.

Finally, the Committee would like to express their appreciation of the help received by the Branch from certain Members of Council and other Senior Members, not forgetting the permanent staff of the Institution.

(Signed) L. G. M. ROBERTS, *Chairman.*
N. C. FRASER, *Hon. Sec.*

Birmingham Branch.—The Committee has pleasure in presenting the Tenth Annual Report, for the year ended December 31, 1932.

At the Annual General Meeting, the following officers for this Branch were elected :—

Mr. A. B. Cameron (*Chairman*).
Mr. R. H. Keath (*Vice-Chairman*).
Mr. L. V. W. Clark (*Hon. Secretary and Treasurer*).
Messrs. B. D. Bailey, E. R. Ward and J. M. Morton (*Committee*).

During 1932, six meetings were held, and the following papers were read :—

January ..	..	"Production Methods in Trinidad and Venezuela," by Mr. C. A. H. Williams.
February	..	"The Recovery of Gasoline by Adsorption," by Mr. R. Fallah.
March ..	..	"Deep Well Pumping," by E. E. Thorneloe.
March ..	..	"High Speed Compression Ignition Engines," by Mr. D. A. C. Dewdney.
May ..	..	"The Latest Improvements in Oil Field Equipment," by Mr. R. B. Rogers.
November	..	"Fuels for Diesel Engines," by Mr. R. Stansfield.

The attendances throughout the year have been consistently good averaging 25 members and visitors.

During the year the Members made the following excursions :—

1. The Metropolitan Carriage and Waggon Works.
2. Hams Hall Power Station.
3. Birch Coppice Cokiery.
4. Wright's Ropes, Ltd.

Four papers were entered for the Student's Medal and Prize from this Section and the paper by Mr. M. E. Kelly, entitled "The Origin and Environment of Petroleum Source Sediments," was highly commended.

(Signed) L. V. WOODHOUSE CLARK
(*Hon. Secretary*).

The President said it would be seen from the reports just read that the remarks he had made at the beginning of the meeting had been well substantiated by the excellent work which the Students' Sections were doing.

Annual Reports of Branches.

The President said Annual Reports had been received from the Branches in Rumania and Trinidad, but the Annual Report from Persia had not yet come to hand.

The Secretary then read the following Annual Reports from the Rumanian and Trinidad Branches:—

Rumanian Branch.—The Committee have pleasure in presenting their Sixth Annual Report for the year ending October 31, 1932, together with the Accounts to that date.

REVENUE ACCOUNT FOR THE YEAR ENDING OCTOBER 31, 1932.

RECEIPTS.

	Lei.
January 19th, 1932 :—	
Grant from I.P.T., London, £22 0s. 0d., at Lei 590	12,980.—
April 5, 1932 :—	
Grant from I.P.T., London, £9 0s. 0d., at Lei 628	5,652.—
	18,632.—

EXPENDITURES.

	Lei.	
Debit from 1931	6,410.20	
Expenses of Reporter at Meetings	2,000.—	
Annual Dinner	1,000.—	
Postage	1,425.80	
Miscellaneous Expenses	450.—	
Printing	262.—	
Balance on Hand	7,084.—	
TOTAL	18,632.—	18,632.—

The following is a list of Members showing in the Branch Register :—

Hon. Members	1
Members	33
Associate Members	10
Students	2
Associates	1
TOTAL	47

This is a decrease of seven as compared with the membership of a year ago. The Branch has not only to regret the loss of these members, but of many supporters outside the Roll of the Institution. The average attendance of Members and Visitors at the Meeting for the year was 27.

THE FIFTH ANNUAL MEETING was held on October 30, at which the Fifth Annual Report was adopted. Messrs. J. L. Chaillet and J. E. Treacy, the two retiring Members of the Committee, were re-elected and Mr. C. R. Young was elected to fill the vacancy caused by the resignation of Mr. F. G. Jackson.

Four General Meetings of the Branch were held during the year and the following papers read and discussed :—

THE THIRTY-THIRD GENERAL MEETING, October 30, 1931—
"Continuous Treating," by J. A. Altshuler.

THE THIRTY-FOURTH GENERAL MEETING, December 18, 1931—
"Production After Gas-Lift," by R. W. Rogers.

THE THIRTY-FIFTH GENERAL MEETING, January 29, 1932—
"Wire Rope Pumping," by P. R. Clark.

THE THIRTY-SIXTH GENERAL MEETING, April 22, 1932—
"Present State of the Hydrogenation Process," by Dr. Ion Edeleanu.

The Fifth Annual Dinner was held on Friday, November 27, 1931, at the National Liberal Club, Ploesti, under the Chairmanship of Capt. Treacy. Forty-two members and their friends were present.

The Committee for the year consisted of the following members :—

Capt. J. E. Treacy (*Chairman and Treasurer*), Capt. T. S. Masterson, Ion Edeleanu, J. L. Chaillet, P. R. Clark, C. R. Young, F. W. Penny (*Hon. Secretary*).

The Committee wish to record their thanks to the Chamber of Commerce, Ploesti, for the use of their Hall for the Meetings of the Branch.

Also to Messrs. C. R. Brasier and W. Bolton for acting as Honorary Auditors for the Accounts herewith presented.

On behalf of the Committee,
(Signed) F. W. PENNY,
Hon. Secretary.

Trinidad Branch.—During the first ten months of the year five ordinary meetings were held, at which the following papers were read :—

January 27 ..	A discussion on Mr. Elias' paper, "Behaviour of Restricted Wells," previously read before the Rumanian Branch.
February 24 ..	"Technical Records for use on an Oilfield," by J. L. Harris, M.C., B.Sc. (Member).
March 30 ..	"Displacement Pumping as applied to Oil Wells," by Albert Millar (Member), the discussion being initiated by F. H. L. Tindall.
April 27	"Some notes on the Mixing and Placing of Cement in Oil Wells," by L. A. Bushe (Member). "A Note on Mudflow," by C. C. Wilson, A.R.S.M. (Associate Member).
September 15 ..	"The Problem of Setting Tubing in newly completed Wells in the Palo Seco Field," by K. W. G. Patterson. At this meeting, Mr. Swigart, of the Shell Petroleum Corporation, and Messrs. Bloemgarten and Holman, of the B. P. M. Co., took leading parts in the discussion.

The average number of members and visitors attending the meetings was 33.

At October 31, there were 26 members on the Roll of the Branch, three having left the Colony and the same number of new members having been enrolled.

The Second Annual Dinner was held at the Queen's Park Hotel, Port of Spain, on October 15, and was followed by a dance. The Branch was honoured by the presence of His Excellency the Acting-Governor, Hon. S. M. Grier, C.M.G., who proposed the toast of "The Institution of Petroleum Technologists," which was replied to from the Chair. "The Industries of Trinidad" was proposed by Mr. G. H. Scott, B.Sc., and replied to by Mr. J. Forbes, President of the Chamber of Commerce, while Mr. J. L. Harris, M.C., B.Sc., proposed the toast of "Our Guests," to which His Honour Mr. Justice Gilchrist responded. The number of members and guests in attendance was 95.

In accordance with instructions that the Annual Report of this Branch should reach London in time to be incorporated in the Report of the Council, it was decided to revert to the last Wednesday in November as the date of the Annual General Meeting.

The Accounts for the period under review have been audited and are laid on the table.

The Committee again wishes to place on record the thanks of all members to Messrs. Middleton and Walsh, the Auditors, for their services to the Branch, and to the President and Members of the Apex Club for the use of their rooms for General and Committee Meetings throughout the session.

(Signed) H. W. REID,
Hon. Secretary.

The President remarked that two excellent Reports had just been read, showing the very good work which the Institution's Branches abroad were doing. The Council had asked the Branches abroad to arrange their Annual General Meetings so that they could send their Reports home to be presented at the Institution's Annual General Meeting. The Council felt that thereby a complete picture of the Institution's work could be formed.

Alterations to By-Laws.

The President said the proposed alteration was a very slight one. The Election Committee felt that the form of application which was in general use could be considerably improved, and, after discussing the matter thoroughly, they had arrived at the form which was set out in the Report, and which had duly been accepted by the Council; but as this particular form of application was incorporated in the by-laws, it was necessary formally to take up the question at the present meeting to obtain the authority of the meeting to this necessary alteration of by-laws. Unless there was any objection to the contrary he would take it that the members agreed with the alteration. (Agreed.)

Re-election of Auditors.

Mr. G. W. Furniss proposed that Messrs. Price, Waterhouse and Co. should be re-appointed auditors for the ensuing year.

Dr. E. R. Redgrove seconded the motion, which was carried unanimously.

(The meeting was then thrown open to visitors.)

Induction of New President.

Mr. James Kewley said it was his pleasant duty to induct into the Chair Mr. T. Dewhurst, but before doing so he desired to make a few remarks. He felt that he could not vacate the Chair without paying tribute to his colleagues on the Council and to the staff of the Institution. The Council were a body of really hard-working men. The attendance at Council and Committee meetings was remarkably high. He could honestly say that he had enjoyed his colleagues' co-operation, had appreciated their support, and perhaps had ignored their criticisms. Their veteran was Mr. Arthur W. Eastlake, who had been Honorary Secretary practically since the very earliest days of the Institution. His

long experience and excellent memory made his advice particularly useful. His interest in his now grown-up child showed no signs of abatement.

He (Mr. Kewley) had to thank, too, all those members of Council who had taken such an active part in the work on various sub-committees, and he had to thank all the other members other than members of Council who had so willingly assisted in that work. Of the staff, Commander R. E. Stoke-Rees, Mr. George Sell, and their assistants he could unhesitatingly speak in terms of praise. Much extra work at present was falling on their shoulders in connection with the World Petroleum Congress—on their willing shoulders he might say; and on that point he would like to make a few remarks about the forthcoming Congress in order to keep the members up to date. All indications pointed to the fact that it would be successful, at least successful as regarded the numbers who would attend. But, of course, about the real success of the Congress—that was, the service which it would render—it was impossible to speak at present. His Majesty's Government had expressed their sympathy with the objects of the Congress, and had shown their practical support by a letter which he had received only yesterday to the effect that they were willing to give a Government reception on one of the evenings, and that a Member of the Cabinet would be present at that reception to receive the delegates. He had also just had a letter from the Foreign Office saying that they had communicated with the Governments of foreign oil-producing countries impressing on them the desirability of sending delegates to the Congress.

He now returned to his pleasant duty of inducting into the Chair Mr. Dewhurst. There was no necessity to introduce Mr. Dewhurst to the members. That would be quite superfluous. He was well known to them all as a member of Council for a long period, as a regular attendant at the meetings, and as a vigorous and active participator in the discussions at the meetings. By a recent ruling of the Council the President-Elect was chosen a few months before the Annual General Meeting. That excellent arrangement allowed the President and the President-Elect to work together so that there could be continuity in the carrying on of the work of the Institution. They could work together to their mutual advantage. In that way Mr. Dewhurst and himself had kept in very close touch during the last few months. The opinion he had formed as to Mr. Dewhurst's suitability for the position of President was one which he was quite sure the members would later endorse and which opinion he knew results would verify. Mr. Dewhurst was a very busy man, but it was generally the case that the busiest people were those who managed to find most time

to take on duties—even onerous duties—such as that of President of the Institution. Personally he could assure the members from experience that the office of President of the Institution was really no light task. It was fitting that a geologist should occupy the Chair now, particularly as the members had had to endure two chemists in succession. But whether they be chemists, geologists or engineers they were all fortunate in having had a scientific training which taught them to think on scientific lines, and so to seek and recognise the value of that co-operation which the constitution of the Institution so well exemplified.

He congratulated Mr. Dewhurst on his accession to the Chair, and he congratulated the members on having Mr. Dewhurst as their President. (Applause.)

Mr. Kewley then inducted Mr. Dewhurst into the Presidential Chair amid the hearty applause of the members.

President's Address.

Mr. Thomas Dewhurst. When I contemplate the list of distinguished men who have passed the Chair I am deeply sensible of the very great honour which the Council has conferred upon me by electing me your President. I thank Mr. Kewley for the felicitous but over-generous terms in which he has inducted me to the Chair; and, gentlemen, I thank you for your generous reception.

Mr. Kewley has explained that he is a chemist, and it only remains for me to add that he is a distinguished chemist. His immediate predecessor is also a distinguished chemist, and despite the eulogy to which you have just listened, I fear that I merely stand to you as having been the Vice-President with the least knowledge of chemistry. However, a complete whole may consist of different but equally essential parts, and I hope that it will not be disadvantageous for the Chair to be occupied for a time by one who is accustomed to measure events by reference to the geological time scale.

When Sir Thomas Holland was inducted to the Chair, he stated that he felt oppressed by the responsibilities he was assuming. I will not pursue the argument to its obvious Euclidian conclusion, but I would state that the great trepidation which I naturally feel in assuming the responsibilities of the Chair are very greatly lessened by the knowledge that all past-Presidents, Vice-Presidents, Members of Council and officers are firmly united in the service of our Institution.

To those who regard the development and application of science as being inevitable and desirable, the history of our Institution affords unalloyed pleasure. The developments that have taken

place in every branch of petroleum technology since our Institution was founded may truly be described as amazing, and we, as an Institution, have every reason to be proud of the part that we have played in those developments.

It is usual to trace oil in its journey from the source-beds to the consumer. The geologist's interest in the journey is slight after the crude has entered the field tanks; while, until very recent years, the chemist's interest only started when the crude reached the refinery. The engineer, however, has always been associated with the oil for the greater part of its journey—which doubtless explains why the engineers form the largest section of our members. It is therefore gratifying that an Engineering Standards Committee of the Council is now in being. In recent years there has been very close liaison between geologists and engineers in respect of the many problems of oil-field development, while the chemist is now taking an important and increasing part even in this work. Indeed, developments in recent years have tended to bring the three main classes of technologists closer and closer together, thus demonstrating the wisdom of our founders in taking the bold step of forming an Institution comprising all classes of petroleum technologists.

Reference has often been made to the triangular structure of our Institution, and to petroleum geology as being the shortest side of this ordinary triangle. This statement has never been strictly correct, as from the beginning administrative experts have been eligible for membership, and therefore geology even in the earliest days was the third side of an ordinary quadrilateral. With the advent of the physicist in recent years geology has been the third side of a pentagon, and in due course we shall probably be joined by other specialists, until the structure of our Institution may be represented by an approximately circular figure.

In recent years no society or institution has been entirely sheltered from the peltings and buffetings of an economic storm unexampled in its scope, duration and severity. It might be shown that the year 1932 included the nadir of this depression, and, if so, then the Report and Accounts for that year, which you have approved this evening, show how well we are weathering the economic storm, and provide eloquent testimony to the inherent strength of our Institution. To have increased the number of issues of our Journal from 9 to 12 per annum in the very middle of the depression is a single and signal act of courage and of enterprise which must be unique amongst societies and institutions.

It may confidently be predicted that with an improvement in general conditions we shall advance from strength to strength, and, in regard to the more permanent factors affecting petroleum

technology, we may rest assured that in the future science will be harnessed to industry more closely and firmly even than at present, and that our particular species will increase in usefulness, number and variety.

In recent years our activities have tended to become increasingly international in character, and this tendency would seem to be inevitable, since the realm of petroleum technology has no frontiers. Our Journal circulates in some 60 countries, and our membership becomes increasingly international. Incidentally, although the centre of gravity of the world's petroleum production appears to be situated at a considerable distance west of Europe, yet it is nevertheless true that the geographical centre of the world's oil-fields is situated at no very great distance from the offices of our Institution.

All these considerations suggest that we are well placed to further developments of petroleum technology in their international aspects. It is therefore meet and fitting that we should have convened, and are now organizing, a World Petroleum Congress. Clearly it is most desirable that technologists from all parts of the world should meet together on a common platform to discuss all important and outstanding problems. One of the most urgent of these is that of the ways and means of obtaining international agreement as to methods of testing petroleum products, and of improving and even creating international machinery to that end. The convening of the Congress is probably the most important and far-reaching step yet taken by the Institution, and doubtless all members will welcome it most heartily, and will do all in their power to make it the great success that it deserves to be.

It is now my very pleasant duty to propose a vote of thanks to Mr. Kewley for the very valuable services rendered by him during his tenure of office in the Chair. It is indeed fortunate for us that Mr. Kewley has been our President during the worst period of the depression ; for, although he is alive to real dangers, he is by nature oblivious of those difficulties and troubles that never happen. He cheerfully undertakes the apparently impossible, and achieves it by unflagging effort. The results of this spirit are to be seen on every hand. It is even impossible to enter our Library, or any single room in our offices, without appreciating the improvements that have been effected by Mr. Kewley. Mr. Kewley had no difficulty in leading us, for his firmness was all the more effective and impressive by reason of the fact that it was exercised only when necessary. I might even say that occasional slight pressure indicated what was beneath the velvet glove. But the outstanding fact about Mr. Kewley is that he worked so hard that he simply carried us all along with him. The

keynote of Mr. Kewley's Presidency has been co-operation. Indeed, it would have been a fitting climax to his Presidency had the World Petroleum Congress been held during the past week; and in this connection it is very gratifying to be able to announce that Mr. Kewley will continue to act as Chairman of the World Petroleum Congress committee. (Applause.)

Gentlemen, I have great pleasure in moving that our best thanks be accorded to Mr. Kewley for his valuable services as President of the Institution.

The resolution was carried by acclamation.

Mr. Kewley, in acknowledging the vote, thanked Mr. Dewhurst for what he had said about him and his activities. He could only promise to follow the custom of all past-Presidents of the Institution, namely, to carry on as far as possible after vacating the Chair. What part there would be left for him to fill after the Congress was over he did not know. It was to be hoped that by that time progress would have been so rapid that some little niche would be found in which he could still work. He thanked the Members for the kind way in which they had endorsed Mr. Dewhurst's remarks, which he very much appreciated. He had really thoroughly enjoyed in every way his two years of occupation of the Presidential Chair.

The meeting then terminated.

The Use of Synthetic Methanol as a Motor Fuel.*

By Donald A. Howes, Ph.D., B.Sc. (Associate Member).

The Properties of Methanol.

Methanol is the simplest member of the series of aliphatic alcohols, and is a colourless liquid of characteristic but not unpleasant odour which boils at 64·7° C. In general appearance it is indistinguishable from ordinary petrols, and it has the advantage of burning with a non-luminous flame and leaving no residue. Like all other alcohols, methanol has a lower calorific value than hydrocarbons, and also, in virtue of its high oxygen content and low molecular weight, a lower calorific value than ethyl alcohol. This is shown in Table I.

Comparing these figures it follows that, at the same compression ratio and overall efficiency, the relative fuel consumptions for a given power output will be :—

No. 1 petrol	100
Ethyl alcohol	161·4
Methanol	221·6

Therefore, as a substitute for petrol, methanol has the great disadvantage of a very low calorific value and consequently a high rate of consumption for a given power output at normal compression ratios. For use in ordinary automobiles the cost of methanol to the user would therefore have to be less than $\frac{100}{221{\cdot}6}$ × price of petrol, to give any saving in fuel cost.

It is obvious, therefore, from calorific value considerations alone that undiluted methanol is not a satisfactory fuel to employ in engines of normal compression ratios, and it follows that the only ways of using methanol as a fuel are : (1) to use much higher compression ratios ; or (2) dilute the methanol with fairly large quantities of other fuel—such as petrol. The utilisation of methanol in two different ways has therefore been considered :—

1. In an undiluted state—for use in engines of special types —*e.g.*, racing cars, etc.
2. The use of petrol-methanol mixtures for all engines normally run on petrol alone—*e.g.*, commercial vehicles and private cars.

The Use of Undiluted Methanol in Engines of Special Types. Knock-resisting Properties.—It is well-known that ethyl alcohol has marked anti-knock properties, and that it can be used at very

* Paper read before Students' Section, London Branch, November 15, 1932

high compression ratios, thus being capable of giving a high power output. Contrary to general belief the same is true with regard to methanol. It has been stated by Ricardo that methyl alcohol obtained from wood naphtha pre-ignites in the E.35 engine at a compression ratio of 5·2, but this observation has not been confirmed.

TABLE I.

Physical Properties.

	Methanol.	Ethy Alcohol.	Motor benzole.	No. 1 Grade petrol.
1. Sp. Gravity 15/15° C.	0·79647	0·795	0·878	0·740
2. Composition: Carbon % ..	37·5	52·2	92·0	85·3
Hydrogen % ..	12·5	13·0	7·7	14·7
Oxygen % ..	50·0	34·8	—	—
Sulphur % ..	—	—	0·3	0·02
3. Freezing Point °C.	—	—	−11°C.	—
4. Calorific value—				
Gross Cals./gram	5,336	7,122	10,025	11,280
B.Th.U./lb.	9,605	12,820	18,050	—
Nett Cals./gram	4,554	6,494	9,620	10,500
B.Th.U./lb.	8,515	11,690	17,320	—
5. Latent heat of evaporation cals./gram at B. Pt.	263	204·5	Benzene = 93·0 Toluene = 86·0	75·0
6. Theoretical air requirements for complete combustion lbs. air/lb. fuel	6·53	9·09	13·21	14·8
7. Kinematic viscosity C.G.S. units				
0° C.	0·0080	0·0179	—	0·0080
10° C.	0·0069	0·0175	0·0083	0·0074
20° C.	0·0059	0·0172	0·0072	0·0068
30° C.	0·0052	0·0168	0·0066	0·0062

Experiments have been carried out in engines of many different types from air cooled motor-cycle engines to supercharged six cylinder racing car engines varying in compression ratio from 6·0 to 15·0—and in no case has pre-ignition been obtained when due care has been taken to ensure adequate cooling. When methanol fuel is used in an Armstrong Whitworth variable compression engine at a speed of 750 r.p.m., perfectly smooth running is obtained at compression ratios up to the maximum available—*i.e.*, 9·4 to 1, at jacket temperatures up to 150° C. At a jacket temperature of 150° C., however—with 9·4 compression ratio and the same speed—slight running roughness occurs. This may, or may not, be due to very slight incipient pre-ignition, but it is scarcely audible and does not promote detonation. An engine of this type has been run with methanol under these conditions for 8 hours continuously, but no more than very slight roughness is evident even after prolonged running. Therefore, there appears to be very little evidence that methanol has pre-ignition tendencies.

It is of interest, in this connection, to note that in some supercharged engines operating at high compression ratios and high boosting pressure, the use of methanol may give severe overheating which may be attributed to pre-ignition. As an instance of this, the case of an 8-cylinder supercharged engine may be quoted. This engine had a static compression ratio of 6·0, and a supercharger boost of 12·0 lb. When run on benzole the performance was satisfactory, while when run on ethyl alcohol the engine did not, as was expected, run colder, but hotter. When methanol was used the trouble was aggravated to such an extent that sparking plug points fused after a few minutes' run. This trouble has been attributed to pre-ignition, but the real cause of the over-heating is the high latent heat of the methanol which increases the volumetric efficiency or, in other words, increases the effective supercharger boost to such an extent that the amount of heat flow to the cooling system is greater than the latter can cope with. This causes the extreme over-heating with methanol, since the latent heat of methanol is 28·6 per cent. greater than that of ethyl alcohol and 179 per cent. greater than that of benzole.

Experiments on supercharged engines of smaller capacity which have been well cooled have shown that methanol is a perfectly satisfactory fuel to employ at static compressions of up to 8·5 to 1, together with supercharger boosting pressures of up to 18 lb./sq. in. gauge. In un-supercharged engines compressions of over 15 to 1 have been used with perfect satisfaction. Because methanol can be used at such high compression pressures, its other very valuable properties can be made full use of. In particular a great advantage may be gained from its very high latent heat of vapourisation.

Table I. shows the latent heat of vapourisation at the boiling point for benzole, No. 1 petrol, ethyl alcohol and methanol.

The latent heat of vapourisation determines the density of the charge taken into the cylinder, since the weight of charge is inversely proportional to its absolute temperature at the moment when the inlet valve closes; in other words, the higher the latent heat of vapourisation of the fuel the greater the volumetric efficiency obtained. In the case of ethyl alcohol, and even more so in the case of methanol, the high latent heat results in a really marked increase in power compared with other fuels, although its total internal energy is lower than that of either petrol or benzole. Moreover, the power output increases very considerably when an over rich mixture is used—a feature not observed to any marked extent with other fuels. This is shown in Fig. 1. This effect is due to the increased volumetric efficiency obtained with rich mixtures owing to the latent heat of the fuel causing a further fall in temperature of the charge. This effect does not obtain to

an appreciable extent when normal petrols or benzole are used, because these are more or less completely evaporated during the suction stroke. In the case of methanol, however, little evaporation occurs during the suction stroke, but mainly takes place during the compression stroke. This has the result of making the compression more isothermal—the temperature of the cycle is lowered—losses due to conduction and to change in specific heat are reduced and the thermal efficiency is increased. These points show why it is that the power output and efficiency obtainable with methanol is considerably greater than with any other fuel yet examined.

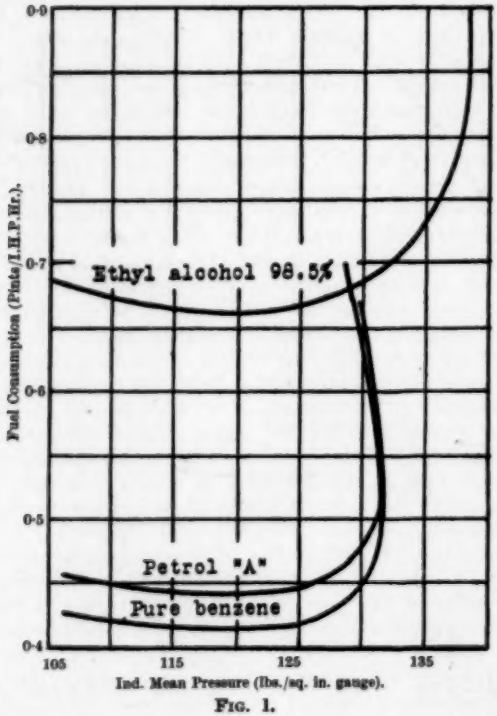

FIG. 1.

VOLUMETRIC EFFICIENCY OBTAINABLE WITH DIFFERENT FUELS.

In all considerations of the maximum power output obtainable from alcohol fuels, volumetric efficiency is of the utmost importance.

Defining this as the ratio of the weight of air drawn into the cylinder per cycle to the weight of air at 0° C. and 760 mms. Hg pressure which would just fill the volume swept by the piston in one stroke, the results of Ricardo show that the variation in volumetric efficiency over a range of mixture strengths for petrol is quite small, and that the former is at a minimum when the mixture strength is that giving just complete combustion, and that

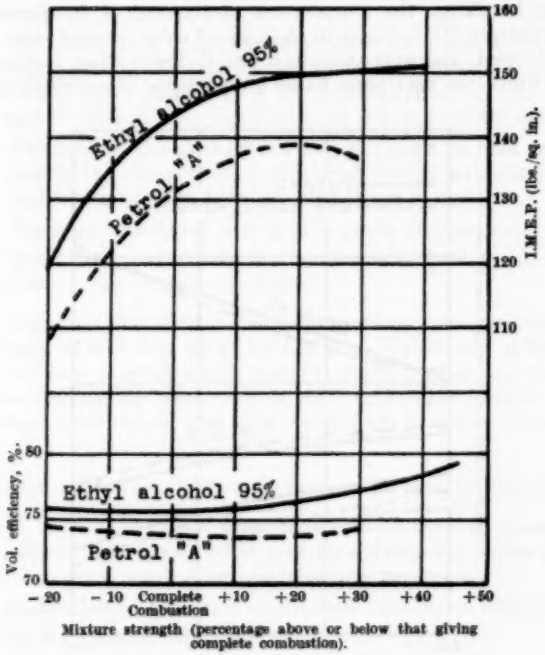

FIG. 2.

it rises slightly as the mixture is either enriched or weakened from the normal. Ricardo's experiments with 95 per cent. ethyl alcohol show that this substance gives a 2 per cent. higher volumetric efficiency than petrol at the theoretically correct mixture strength, but about 3-3·5 per cent. higher for richer mixtures. This is shown in Fig. 2.

Thermal Efficiencies.

Alcohol fuels give a higher thermal efficiency than hydrocarbon fuels, due to the following effects :—

(*a*) Reduction in the temperature of the cycle due to the evaporation of alcohol during the compression stroke.
(*b*) The consequent reduction in heat loss.
(*c*) Lower flame temperature.

For a given compression ratio at which petrol can be used without knocking, the temperature at the end of compression is approximately 70° C. lower in the case of ethyl alcohol than when petrol is used, and approximately 100° C. lower when methanol is used. Since the maximum flame temperature of an ethyl alcohol

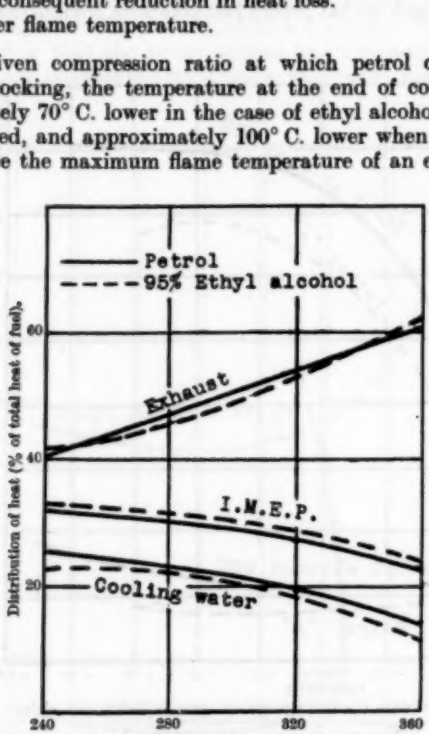

Fig. 3.

RICARDO'S RESULTS. (COMPRESSION RATIO 5.45 TO 1.)

mixture is also about 100° C. lower and in the case of methanol about 130° C. lower, it follows that the highest flame temperature attained with ethyl alcohol and methanol fuels will be approximately 170° C. and 230° C. respectively lower than that of a petrol mixture, and the loss of heat to the jackets and that due to change

of specific heat, etc., will be substantially reduced. Again, when running with both alcohols, the total weight of the working fluid is greater, as pointed out previously; hence the relative loss of heat will be even slightly less than would appear from a consideration of the temperature above.

These considerations are, however, based upon a very low compression ratio—namely, 5–6 to 1. The figures quoted for ethyl alcohol are due to Ricardo, who found that at compression ratios of 5 to 1—7 to 1 ethyl alcohol gave a thermal efficiency 2·5 per cent. higher than petrols.

Fig. 3, which is a graphical illustration of some of Ricardo's experiments, shows the distribution of heat with both petrol and 95 per cent. ethyl alcohol at a compression ratio of 5·45 in the E.35 engine. It will be noticed that, in the case of the alcohol—

(*a*) The heat to the exhaust is about the same as with petrol—due to the compensating effects of smaller exhaust volume and higher specific heat of exhaust products.

(*b*) The heat transferred into usable power is greater.

(*c*) The heat going to the jacket water is less—indicating a lower mean cycle temperature.

It is regretted that similar curves for methanol are not available, but it may be said that with this fuel the exhaust heat is less, the amount of heat converted into useful power is greater and the heat going to the cooling water is less than with ethyl alcohol. The advantages of methanol over ethyl alcohol are therefore obvious.

Maximum Power Output Obtainable from Methanol.

It will be seen from the foregoing remarks that on theoretical considerations, methanol should give an appreciably higher power output than ethyl alcohol for the following reasons:—

(*a*) Higher latent heat and consequent volumetric efficiency.

(*b*) Higher thermal efficiency,

and moreover, that it should give a lower engine operating temperature. These expectations have been realised in a large series of engine trials, with the result that methanol has been established as a racing fuel without equal where maximum power output is required at any cost. Naturally its low calorific value and high rate of consumption is a disadvantage which prevents its use in long distance races, where the weight of fuel carried must be reduced to the minimum. In such cases it cannot compete with a light hydrocarbon fuel doped with tetra ethyl lead.

Engine Results.

Experiments on Single Cylinder Motor Cycle Engines.—Motor cycle engines are, except for a few isolated cases, air cooled, and are expected to run for long periods at high operating temperatures. Compression ratios are high, and due to the high temperatures developed, the pistons, cylinders and valves must be designed with a view to withstand most exacting conditions. Therefore any fuel which can be satisfactorily used at the high compression ratios employed, and also give a cooler engine under load, is of great value. This is especially true in the case of racing engines—particularly those used in dirt-track work, where the engine is kept running at high speeds in low gear when air cooling is inefficient and insufficient for the amount of power being developed. Therefore the cooling effect of methanol is as important as the higher output that is obtainable by its use, because it gives better reliability.

Experiments on Motor-Cycle Engines.—As an example of the value of methanol as a racing fuel the following results on a 500-cc. single-cylinder motor-cycle engine may be quoted. The engine concerned was one of a very well-known make fitted with overhead valves and operating on the four-stroke cycle. Fig. 4 shows the increase in power output that is obtained by increasing

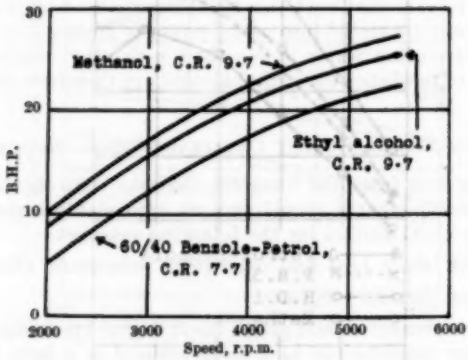

Fig. 4.

500 c.c. 4-stroke motor-cycle engine.

the compression ratio from 7·7 to 9·7 and substituting methanol and ethyl alcohol for a petrol-benzole mixture. This shows that ethyl alcohol at the latter compression ratio gives 13·7 per cent. more power than benzole at the lower compression ratio. Methanol

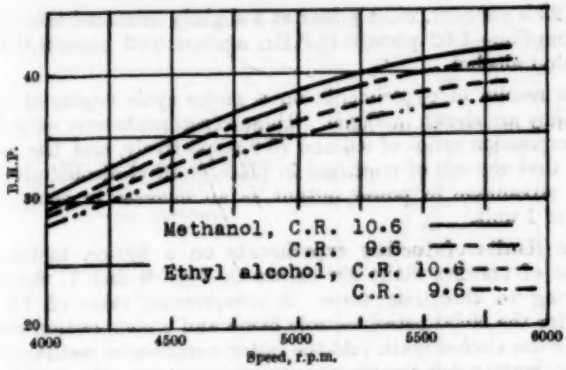

FIG. 5.

RESULTS ON METHANOL AND ETHYL ALCOHOL AT COMPRESSION RATIOS OF 9·6 AND 10·6 TO 1.

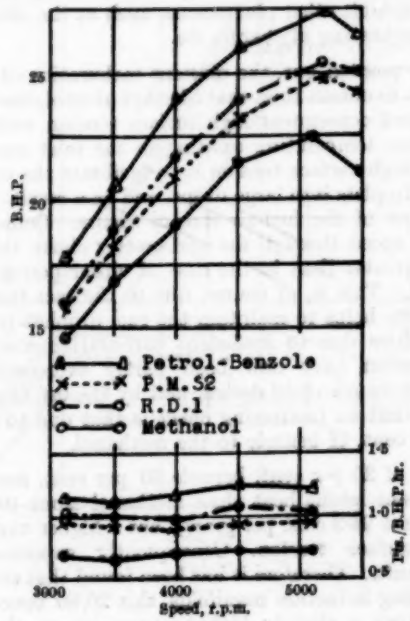

FIG. 6

gives 23·3 per cent. more power at a slightly increased rate of fuel consumption—1·02 pints/B.H.P.Hr. against 0·92 pints/B.H.P.Hr. for ethyl alcohol.

The results of experiments on a motor-cycle engine of higher efficiency are shown in Fig. 5. These experiments were carried out at compression ratios of 9·6 and 10·6 respectively, and the results show that the use of methanol in place of ethyl alcohol gives the same advantage in power output as an increase in compression ratio of 1 unit.

The results of further experiments on a 500-cc. motor-cycle engine of another make are shown in Figs. 6 and 7, the latter referring to throttling tests. A compression ratio of 7·0 was used for the 50/50 petrol-benzole blend and a compression ratio of 8·0 for the alcohol fuels. At the latter compression methanol gave approximately 6–8 per cent. greater power than the fuel R.D.1, which consists essentially of ethyl alcohol.

Experiments in Multi-Cylinder Engines.—Tests in a wide range of multi-cylinder engines confirm those made in single-cylinder engines, but exhibit other phenomena, such as the effects of distribution and preheating of charge, etc.

As already pointed out, the efficient carburation of methanol is more difficult to obtain than that of ethyl alcohol, due to the high latent heat and consequent high surface tension, and low vapour pressure at the temperature existing in the inlet manifold. The effect of the high surface tension is to facilitate the coalescence of small liquid droplets into large drops, and as a result precipitation of the fuel out of the fuel-air stream occurs. Consequently the optimum air speed through the carburetter choke tube and inlet manifold is greater than in the case of either petrols, benzole or ethyl alcohol. This is, of course, due to the fact that a high air stream velocity helps to maintain the fuel droplets in suspension. Early difficulties due to inefficient carburation and consequent poor distribution have now been partly overcome by proper attention to inlet manifold design, and by the use of the optimum air velocity—but an interesting effect is that due to the addition of 20–30 per cent. of benzole to the methanol.

A mixture of 20 per cent. benzole 80 per cent. methanol has a somewhat lower latent heat than methanol alone (90·4 cals. per gram as against 94·3 cals. per gram), but a higher vapour pressure and lower surface tension. Consequently vaporisation is not quite so difficult. Therefore it has been found that on two engines fitted with long induction manifolds this 20/80 benzole-methanol blend has given a slightly higher power output than methanol

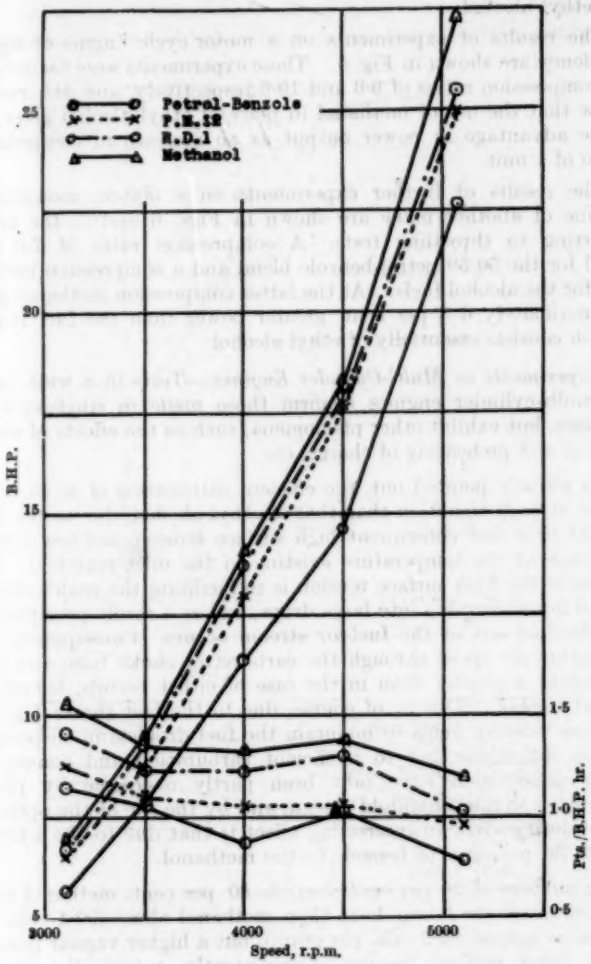
Petrol-Benzole
P.E.12
R.D.1
Methanol
B.H.P.
25
20
15
10
5
1·5
1·0
0·5
Pts./B.H.P. hr.
3000
4000
5000
Speed, r.p.m.

FIG. 7.

alone at high engine speeds. This is illustrated by the results on a four-cylinder engine, 11 to 1 compression ratio, shown in Fig. 8. It should be noted, however, that in the majority of engines the higher the methanol content of the fuel the higher the maximum power output.

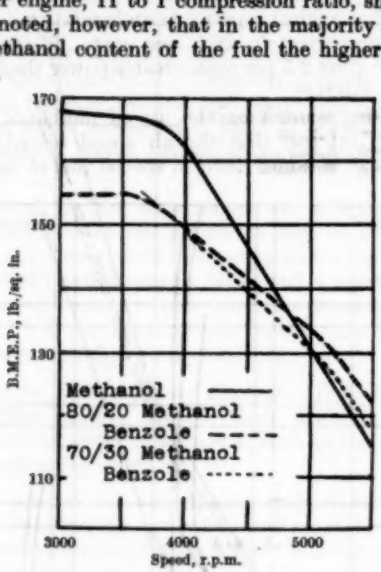

FIG. 8.

4-CYLINDER ENGINE. COMPRESSION RATIO 11 TO 1.

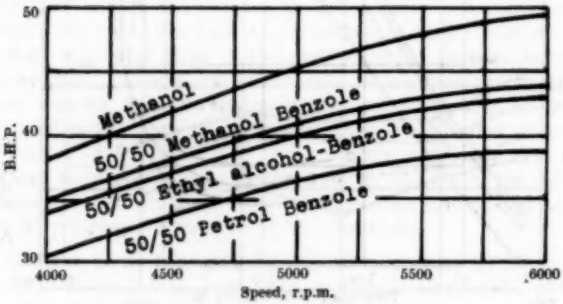

FIG. 9.

4-CYLINDER ENGINE, SUPERCHARGED.

The results of tests in a supercharged four-cylinder engine of low capacity and 5 to 1 compression ratio are shown in Fig. 9.

These tests show the large increase in power obtainable by the use of methanol as against a petrol-benzole mixture. This increase in power is approximately 26.5 per cent. A 50/50 methanol-benzole mixture gives 2·5 per cent. greater power than a 50/50 ethyl alcohol-benzole mixture.

As a concluding remark on the use of methanol in high duty engines, it is of interest that the air speed record now held by Great Britain was obtained using a special fuel of which synthetic

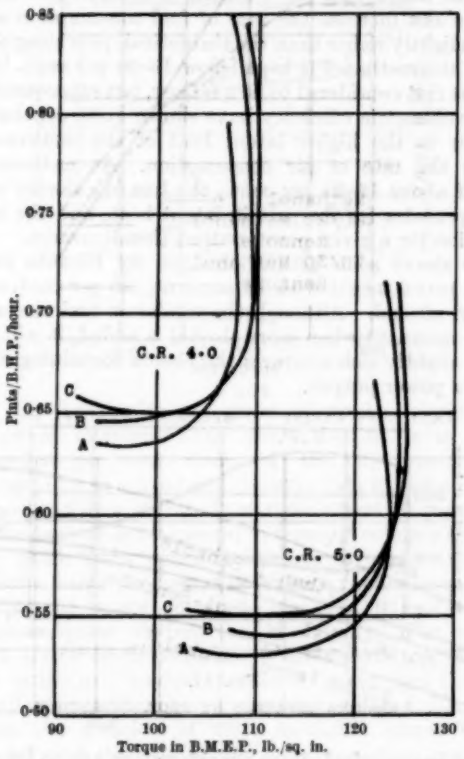

FIG. 10.

RESULTS IN E.35 ENGINE.

Full throttle; 1500 r.p.m.; air heating; 1350 watts; water temperature 60° C.

A.	90	per cent.	heavy Calif. std.	+10	per cent.	ethyl	alcohol.
B.	85	,,	,, ,,	+15	,,	,,	,,
C.	80	,,	,, ,,	+20	,,	,,	,,

methanol was the major constituent. This methanol was manufactured by Messrs. Imperial Chemical Industries, Ltd., at Billingham.

The Use of Methanol as a Fuel when Mixed with Petrols.

The satisfactory use of methanol as a constituent of ordinary motor fuels depends upon the proper combination of cost, power output and rate of fuel consumption, and this has been simplified since it was found that the addition of methanol to an ordinary petrol does not increase the rate of fuel consumption at mixture strengths slightly richer than the theoretical, providing the concentration of the methanol is kept below 15–20 per cent. by volume. This was at first considered to be a fallacy, but subsequent measurements of volumetric efficiency have shown quite conclusively that this is due to the higher latent heat of the methanol mixture increasing the rate of air consumption. At methanol concentrations of above 15–20 per cent., the loss in calorific value more than compensates for the gain in latent heat, and the rate of fuel consumption for a given power output then increases.

Fig. 10 shows some results obtained by Ricardo on an E.35 engine on petrol mixed with 10 per cent., 15 per cent. and 20 per cent. ethyl alcohol. Although the minimum fuel consumption is, of course, increased when more alcohol is added, it will be noticed that with slightly rich mixtures the blends containing alcohol give the greater power putput.

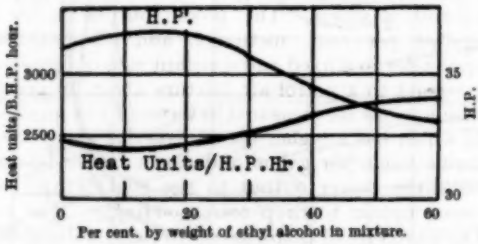

Fig. 11.

Results obtained by Prof. Hubendick.

As already remarked, these considerations are no longer true for ethyl alcohol or methanol concentrations greater than 15–20 per cent. This is shown in Fig. 11, which presents some results obtained by Prof. Hubendick in Sweden. These results show that, for a given carburetter setting comparable to that used on multi-cylinder automobile engines, the horse-power power-output slowly

rises with increasing ethyl alcohol content up to 20 per cent. by volume, and then rapidly decreases. Similarly the fuel consumption (in heat units) for a 20 per cent. ethyl alcohol mixture is practically the same as for petrol alone, but increasing alcohol contents give a higher rate of fuel consumption.

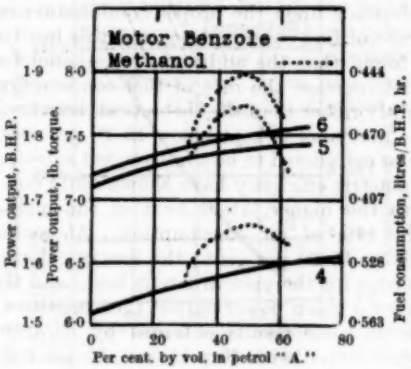

FIG. 12.

POWER OUTPUTS AND FUEL CONSUMPTIONS OF METHANOL BLENDS AT COMPRESSION RATIOS OF 4, 5 AND 6, CONSTANT FEED RATE.

In Fig. 12 the results are given of similar experiments on methanol-petrol mixtures. The power output is in this case plotted against per cent. methanol, and all measurements of power output refer to a fixed and constant rate of fuel consumption which correspond to a petrol air mixture about 10 per cent. rich. As fuel consumptions are measured in terms of volumes the addition of benzole, which has a higher specific gravity and consequently a larger calorific value per gallon and also a higher latent heat per gallon, causes the power output to rise slightly and also causes the fuel consumption to drop correspondingly. The addition of methanol to a mixture of petrol and benzole containing 30 per cent. of benzole results in a marked increase in power, and this is maintained until the methanol concentration reaches 20 per cent., after which the addition of more methanol causes the power output to fall and the rate of fuel consumption to rise.

These figures have been obtained at compression ratios of 4·0, 5·0 and 6·0, and under the engine conditions employed neither of the fuels are knocking. The use of higher compression ratios at which some of the low value fuels do knock are shown in Fig. 13. Taking the results obtained at a compression ratio of 8 to 1, at

which every fuel except that containing 20 per cent. of methanol knocks—the ones containing less benzole knocking heavier than those containing more benzole—it will be seen that as methanol is added to a mixture of petrol and benzole containing 50 per cent.

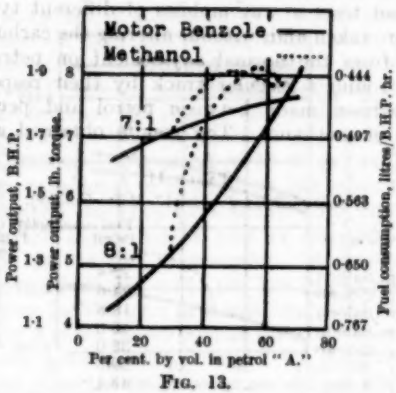

FIG. 13.

POWER OUTPUT AND FUEL CONSUMPTIONS OF METHANOL BLENDS AT COMPRESSION RATIOS OF 7 AND 8, CONSTANT FEED RATE.

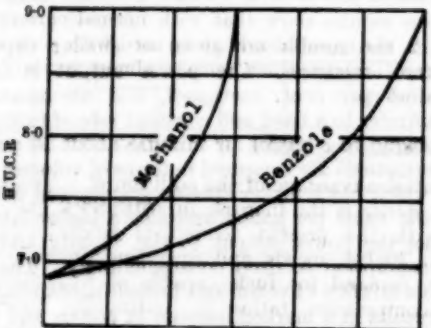

FIG. 14.

ARMSTRONG-WHITWORTH VARIABLE COMPRESSION ENGINE.

benzole, the power output increases very rapidly. This is partly due to the thermal properties of the methanol, but is mostly due to the decrease in knocking which results. It will be noticed,

however, that the blend which contains 20 per cent. of methanol, and which does not knock under these conditions, still shows the greatest power output and that an increase in the methanol concentration gives a falling power curve.

These experiments on single cylinder engines have been confirmed by actual road tests in automobiles of different types. A series of 10 cars were taken and, without altering the carburettor settings in any way from the normal adjustment on petrols, these cars were driven round a circular track by their respective owners, and a comparison made between petrol and petrol containing 10 per cent. of methanol. The results obtained are reproduced in Table II.

TABLE II.

Result of Road Trials (17 *Miles Course*).

Type of Car	Fuel consumption (MPG)	
	Petrol	Petrol + 10% methanol.
12 h.p. Saloon..	22·8	23·8
12 h.p. 2-Seater	24·6	25·0
16 h.p. Saloon..	18·8	20·6
8 h.p. Saloon..	46·0	41·4
12 h.p. 2-Seater	32·0	32·4
9 h.p. Saloon..	29·3	29·2
7 h.p. Saloon..	43·1	45·2
15 h.p. 4-Seater	23·6	24·8
7 h.p. 4-Seater	44·7	44·2
14 h.p. Saloon..	19·1	19·8

All these results show that with normal carburettor settings a 10 per cent. methanol blend can be used with perfect satisfaction, and that fuel consumptions remain almost exactly the same as with petrol alone.

THE ANTI-KNOCK VALUE OF METHANOL-PETROL MIXTURES.

The greatest advantage of the addition of methanol to ordinary petroleum spirits is the increase in anti-knock value that results, because with the present tendencies towards smaller engines running at higher speeds and operating at higher compression ratios, the demand for fuels capable of withstanding knocking at high compression ratios is continually increasing. When mixed with petrol, methanol has an anti-knock value 1·8–2·0 times that of benzole—*i.e.*, the addition of 10 per cent. of methanol to a petrol increases the knock rating of the latter to the same extent as the addition of 18–20 per cent. benzole.

The results of tests on the anti-knock value of methanol petrol mixtures are given in Fig. 14. These results were obtained on an Armstrong Whitworth variable compression engine, but exactly similar results are obtained on engines of different types, such as

the Horning engine, the Ethyl Gasoline Series 30 engine and the Ricardo engine. Other results are shown in the Fig. 15, but in this case the value of methanol additions is given in terms of tetraethyl lead and octane-heptane blends instead of compression ratio variations.

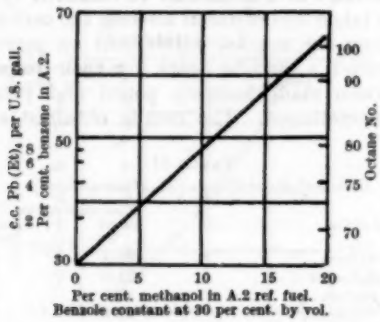

FIG. 15.

ETHYL GASOLINE S.30 ENGINE, 150° C. JACKET TEMPERATURE.

For use in air cooled engines it is essential that any spirit used should retain its anti-knock properties at high engine temperatures, and in this respect methanol has the advantage of having the same anti-knock value (relative to benzole) at an engine jacket temperature of 150° C. as at 100° C. As an anti-knock blending material methanol is slightly superior to ethyl alcohol, and is thus the most valuable material that exists in large quantities for the improvement of the knock ratings of commercial spirits—with the exception of such dopes as tetraethyl lead.

THE MISCIBILITY OF METHANOL WITH OTHER MOTOR SPIRITS.

Unfortunately methanol suffers from the great disadvantage that there are very few petrols with which it is miscible in all proportions at ordinary temperatures, even when it is perfectly dry, whereas anhydrous ethyl alcohol is perfectly miscible with all petrols at the same temperatures.

The solubility of methanol in any hydrocarbon depends upon :—

(*a*) Temperature.

(*b*) The presence of water.

(*c*) The molecular configuration and physical properties of the hydrocarbon.

In general the lower the temperature the more narrow are the limits of miscibility between methanol and a hydrocarbon, while the presence of water has a marked effect in the same direction. The same generalisations apply to the higher aliphatic alcohols, such as ethyl alcohol, but in these cases the effects of temperature and the presence of water are not so well marked.

TABLE III.

Hydrocarbon.	Aniline Point.	Methanol Solubility. % by volume. −20°	−10°	0°	+10°	+20°
n-Pentane (B.D.H.) ..	—	3·2	4·3	7·1	12·8	Miscible in all proportions.
iso-Pentane (B.D.H.) ..	—	3·7	5·6	9·9	Miscible in all proportions.	
n-Hexane (B.D.H.) ..	57° C.	2·4	3·6	5·6	9·1	24·7
n-Heptane (B.D.H.) ..	68·9° C.	0·9	1·9	3·0	4·5	6·7
Pure n-Heptane	69·7° C.	0·4	1·1	1·9	2·8	4·1
2.2.4 Trimethyl Pentane ..	79·6° C.	—	—	2·1	3·9	5·1
Cyclohexane	31° C.	Cyclohexane crystallises.			3·3	4·8
Methyl Cyclohexane ..	41° C.	—	1·4	2·1	3·1	4·1
Cyclohexene	−20° C.	7·4	11·8	24·2	Miscible in all proportions.	
2.2.4 Trimethyl Pentene	−2 32·2° C.	Miscible in all proportions.				
Octene 1 and 2 mixture ..	—	—	20·7	—	—	—
Trimethyl-ethylene ..	11° C.	Miscible in all proportions.				
Amylene mixture	14·0° C.	Miscible in all proportions.				
Diethyl-methyl-ethylene ..	−40° C.	Miscible in all proportions.				

Of the four main classes of hydrocarbons—namely, paraffins, naphthenes, aromatics and unsaturateds—methanol is the least soluble in the normal paraffins and the most soluble in the aromatics, and is, in nearly all cases, more soluble in unsaturateds than in naphthenes. This generalisation is only true, however, when comparing hydrocarbons of different classes which have the same boiling point, for in all classes of hydrocarbons the solubility of methanol decreases with rise in the boiling point and molecular weight of the hydrocarbons. Thus methanol is more soluble, at a given temperature, in normal pentane than in normal heptane ; similarly it is more soluble in cyclohexane then in the substituted cyclohexanes and more soluble in low-boiling olefines than in high-boiling aromatics. It is also noteworthy that methanol is more soluble in branched chain paraffins than in the normal homologues. Some figures for the solubility of methanol in various hydrocarbons are shown in Table III. The fact that methanol has a lower solubility in pure n-heptane (ex Pinus Sabiniana) than in B.D.H.

n-heptane is accounted for by the fact that the latter contains naphthene impurities. The effects of these impurities are also shown in Fig. 16.

From the figures given in Table III. it is obvious that no definite relationship exists between the aniline point of a hydrocarbon and its solvent power for methanol. This important fact is also evident from the data plotted in Fig. 17, which refers to the solubility of methanol in various petrols and petrol fractions. It will be noticed, however, that *in general* the lower the aniline point the higher the methanol solubility.

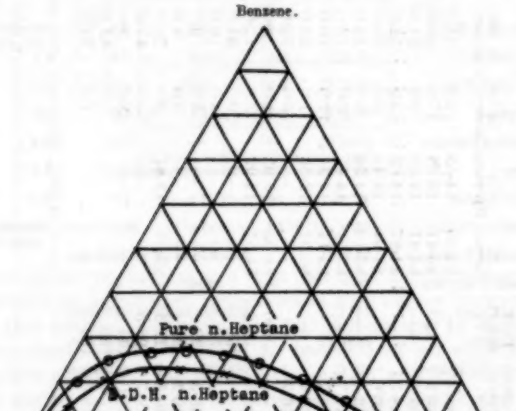

FIG. 16.

Table IV. shows the solubility of methanol at temperatures of −10° C. and 0° C. in various petrols and indicates that :—

(*a*) With the exception of benzole mixtures methanol is only soluble in market spirits to a negligible extent at −10° C. Therefore a blending agent is always necessary.

(*b*) In the case of cracked spirits an olefine content of 20 per cent. has a negligible effect on methanol solubility.

(*c*) Reduction in average boiling point causes a greater increase in methanol solubility than the presence of the olefines normally met with in cracked spirits.

TABLE IV.

The Solubility of Methanol in Various Petrols.

			Sp. Gr. 15°/15°C.	Aniline Point °C.	I.P.T. mid-Pt. °C.	% Carbon.	% Hydrogen.	% Unsaturateds.	% Aromatics.	% Naphthenes.	% Paraffins.	Methanol solubility % by volume. −10° C.	0° C.
English market spirit	A.1	..	0·7390	48·8	—	85·50	14·55	3·0	15·0	33·0	49·0	0·5	2·4
" " "	B.1	..	0·7377	46·5	120	85·41	13·93	17·0	20·0	13·0	50·0	1·0	3·85
" " "	C.1	..	0·7283	57·1	—	84·41	14·52	9·0	14·0	22·0	55·0	1·0	3·85
" " "	D.1	..	0·7334	48·2	—	84·97	14·62	3·0	12·0	41·0	44·0	0·5	2·9
" " "	E	..	0·7307	46·6	—	84·84	14·43	2·0	19·0	25·0	54·0	0·5	2·4
" " "	F	..	0·7191	52·1	—	85·19	14·24	9·0	13·0	19·0	59·0	2·4	3·4
" " "	G	..	0·7570	47·7	—	85·51	14·41	10·0	10·0	53·0	27·0	0·5	1·0
" " "	H	..	0·7559	47·7	—	85·14	14·34	12·0	10·0	49·0	29·0	0·5	1·0
Market benzol mixture	K	..	0·7774	20·6	—	86·92	12·55	1·0	53·0	9·0	37·0	23·7	40·2
Benzol mixture	L	..	0·7609	26·7	—	—	—	6·0	36·0	23·0	35·0	15·0	43·0
Casing head gasoline	M	..	0·6711	—	59·0	84·03	15·93	1·0	3·0	41·0	55·0	2·4	3·3
Aviation spirit	N	..	0·7168	50·5	94·0	84·57	14·92	2·0	12·0	56·0	30·0	2·5	4·0
Cracked spirit	O	..	0·7738	—	156	—	—	20·0	34·0	46·0	45·6	1·5	3·5
" "	P	..	0·7529	—	138	—	—	13·0	16·0	26·0	45·0	2·0	2·7
Mid continent straight run		..	0·7388	56·3	122	—	—	4·0	9·0	35·0	52·0	0·5	2·1
California straight run		..	0·7564	50·2	125	—	—	3·0	8·0	61·0	28·0	0·5	2·6
Spirit	R	..	0·7670	30·3	112·5	85·96	13·81	3·0	26·0	55·0	16·0	2·4	3·3
"	S	..	0·7958	18·7	128·5	—	—	3·0	41·0	44·0	12·0	4·3	5·2
"	T	..	0·7786	47·0	144	—	—	Nil	9·0	91·0	Nil	1·0	1·0
"	V	..	—	−16·0	160	—	—	2·0	63·0	26·0	9·0	19·4	30·0
"	W	..	—	39·6	150	—	—	1·0	14·0	52·0	33·0	1·0	2·2

Unsaturateds determined by measuring the loss to two volumes of 80% sulphuric acid, and adding this to the amount of polymerised material formed.

Aromatics determined by the difference in aniline point before and after treatment with two volumes of 98% sulphuric acid.

Naphthenes and Paraffins determined by Garner's Method (*J. Inst. Petr. Techn.*, 1928, **14**, 695).

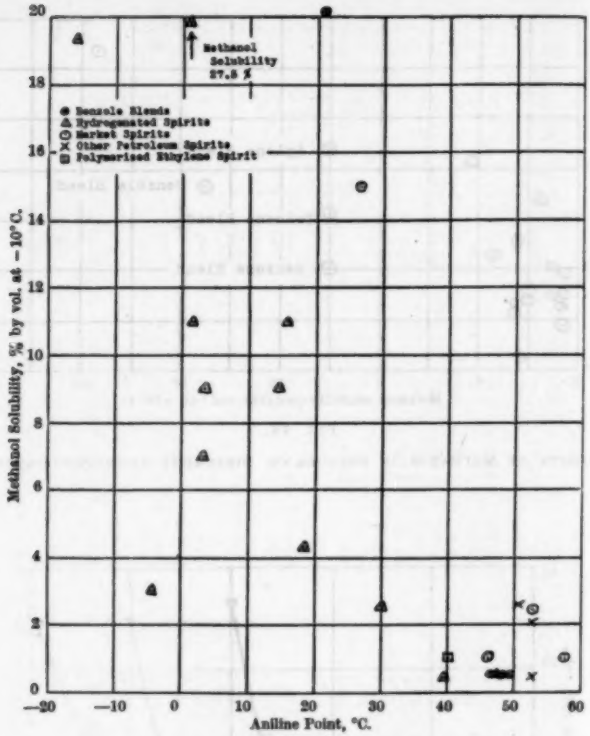

FIG. 17.

ANILINE POINT AND METHANOL SOLUBILITY AT −10° C.

(*d*) Methanol is more soluble in benzole mixture K, which contains 53 per cent. of total aromatics and 30 per cent. of benzole, than in spirit V, which contains 63·2 per cent. of aromatics. The reason for this is explained later.

(*e*) Methanol has the same solubility at −10° C. in casing head gasoline M of mid-point 59° C. and aromatics=2·7 per cent., as in spirit R of mid-point 112·5° C. containing 25·8 per cent. aromatics. This illustrates the importance of volatility upon methanol solubility.

(*f*) Gasolines can be produced which are capable of dissolving quite large amounts of methanol without the addition of a blending agent.

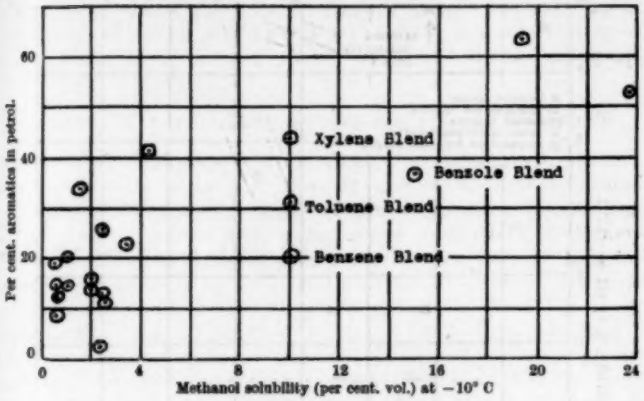

FIG. 18.

SOLUBILITY OF METHANOL IN PETROLS OF DIFFERENT AROMATIC CONTENTS.

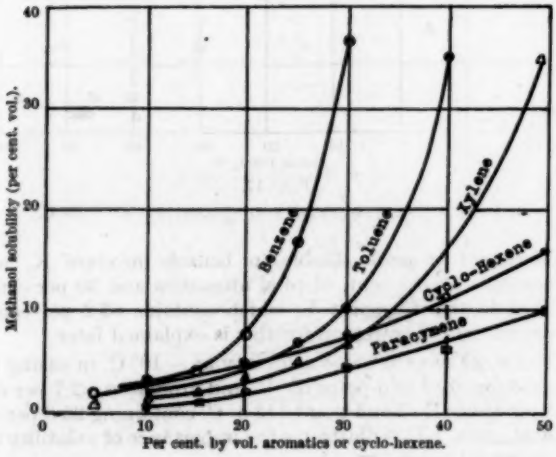

FIG. 19.

SOLUBILITY OF METHANOL IN BLENDS OF PETROLEUM ETHER (100 TO 120° C.) WITH AROMATICS AND CYCLO-HEXENE.

Fig. 18 shows that no definite relationship exists between the aromatic contents of petrols and the solubility of methanol therein. This point is dealt with later.

Blending Agents for Methanol-Gasoline Mixtures.

As already pointed out, methanol is more soluble in aromatics than in other hydrocarbons, therefore a mixture of methanol and gasoline may be brought into one liquid phase by the addition of aromatics. The choice of aromatics is, however, limited by the fact that the efficiency of these compounds in this direction falls off rapidly with rise in boiling point, benzene being by far the most effective. This is illustrated in Fig. 19, which shows the solubility of methanol at 0° C. in blends of benzene, toluene, xylene, para-cymene and cyclohexene in 100°–120° C. aromatic-free petroleum ether. It will be observed that cyclohexene is more efficient than para-cymene as a blending agent in all concentrations up to 50 per cent. and more efficient that xylene in all concentrations up to 35 per cent.

Fig. 20 shows that to hold 10 per cent. of methanol in solution

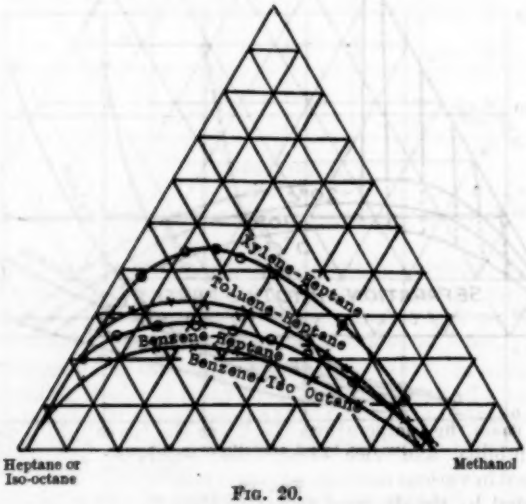

Fig. 20.

AROMATICS AS BLENDING AGENTS.

Iso-octane=2.4.4 Trimethyl Pentane.

in pure normal heptane at −10° C. the following amounts of aromatics are necessary :—

Benzene 25·5 per cent. by volume.
Toluene 32·0 per cent. by volume.
Xylene 44·0 per cent. by volume.

This adequately explains why there is no definite relationship between the solubility of methanol and the aromatic hydrocarbon contents of the gasolines in which it is dissolved. The solubility of methanol in any petrol or hydrocarbon is dependent to a marked

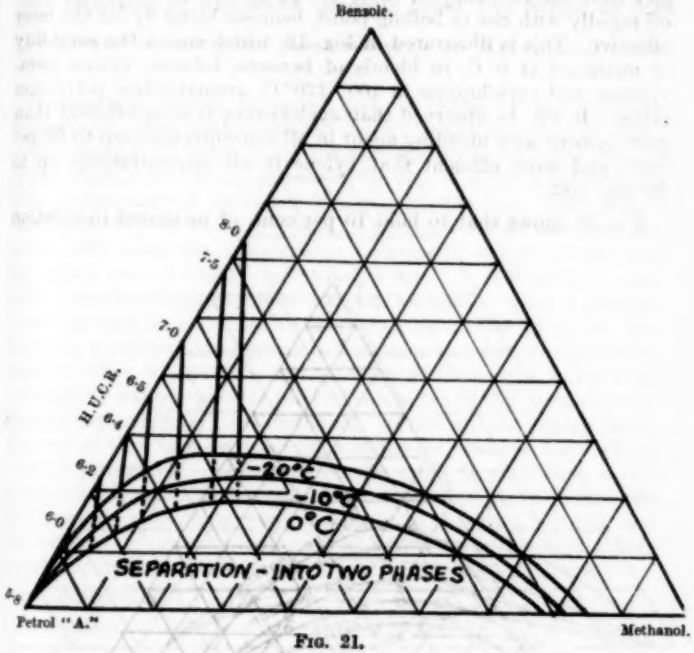

FIG. 21.

extent upon the temperature, the lower the temperature the lower the solubility and vice versa. The solubility relationships of methanol in various mixtures of petrol and benzole are conveniently illustrated by the diagram shown in Fig. 21. The petrol referred to in this diagram is a typical English market spirit and it will be observed that, as already remarked, the range of miscibility is

decreased to an appreciable extent at the low temperatures. Thus, to hold in solution 10 per cent. of methanol, there is required :—

15·0 per cent. of benzole at 0° C.
21·0 per cent. of benzole at −10° C.
26·5 per cent. of benzole at −20° C.

There are other compounds, however, which are much more effective than benzole in promoting the miscibility of methanol and petrol, and the results of much work on this phase of the subject have been published in the literature. The compounds which are most effective in this direction are higher boiling alcohols, such as propyl and butyl alcohols, which can be produced synthetically in exactly the same way as methanol—and also ethyl alcohol and cyclohexanol. The effects of these substances are shown in Fig. 22 on which the curve for benzole is added for the sake of comparison. Thus a mixture with petrol containing 10 per

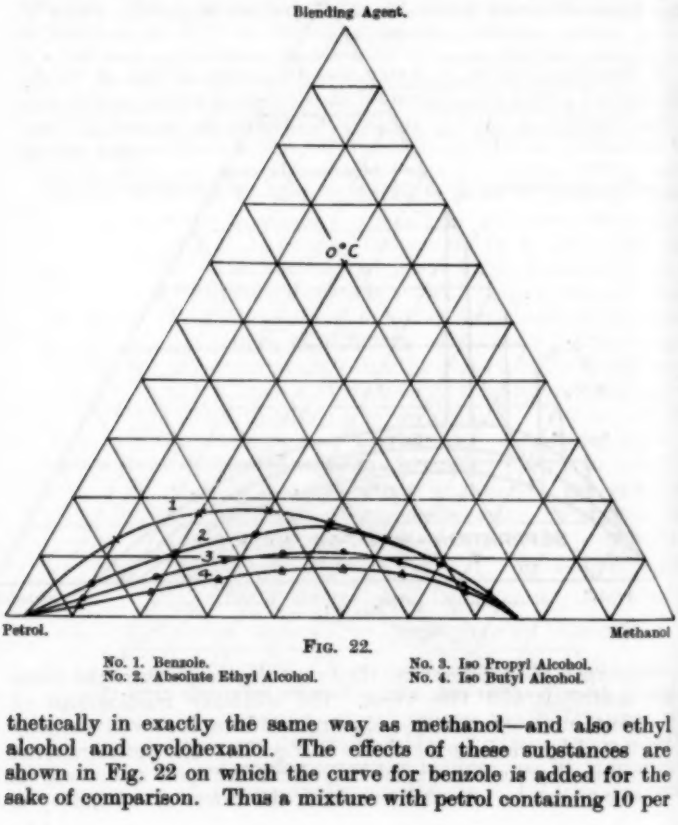

FIG. 22.

No. 1. Benzole.
No. 2. Absolute Ethyl Alcohol.
No. 3. Iso Propyl Alcohol.
No. 4. Iso Butyl Alcohol.

cent. of methanol, and 2·4 per cent. of isobutyl alcohol is miscible with petrol at all temperatures above 0° C. and it is, therefore, possible to use such a mixture as a motor fuel. Both the methanol and the isobutyl alcohol can be made simultaneously in the same plant by the catalytic treatment of water gas. The addition of higher alcohols such as isobutyl alcohol—to normal petrols—produces effects similar to those caused by the addition of methanol because these substances have, like methanol, a high anti-knock value; moreover they are clean water white liquids, which do not deteriorate during storage if properly refined. Compared with methanol, they have higher calorific values and lower latent heats.

The Effect of the Addition of Water to Methanol-Petrol Blends.

Methanol is soluble in water, and in virtue of this property mixtures of petrol with methanol dissolve small amounts of water—this amount of water being proportional to the alcohol content of the mixture and being greater in the case of ethyl alcohol blends than in the case of methanol blends. If, however, more than a small quantity of water is added, it causes a separation into two layers—the lower one of which is a methanol-water mixture and the upper one of which consists of petrol. It will thus be seen that a methanol-petrol blend has an advantage over a straight petrol in that it will dissolve the small quantities of water that normally separate out of petrol in fuel lines and filters and thereby cause trouble, whereas the adventitious addition of a fairly large quantity of water separates the fuel mixture and the most valuable constituent—namely, the methanol, is lost in the water layer. Because of this, it is essential for a methanol blend to have a high "water tolerance"—*i.e.*, its properties must be such that it will dissolve an appreciable amount of water before separation into two layers occurs. Defining water tolerance in this way, we find that the amount of water which can be added to a methanol blend before separation occurs depends upon the following factors :—

1. Temperature.
2. Amount of methanol present in the blend.
3. Excess of blending agent, *e.g.*, benzole present in the blend.

The effect of temperature upon miscibility relationships has already been pointed out, and it follows from this that the lower the temperature the smaller the water tolerance of a given blend. This is shown in Fig. 23, which refers to a petrol-methanol mixture containing 10 per cent. of methanol, which has been on sale to members of I.C.I. staff at Billingham for the past two years and

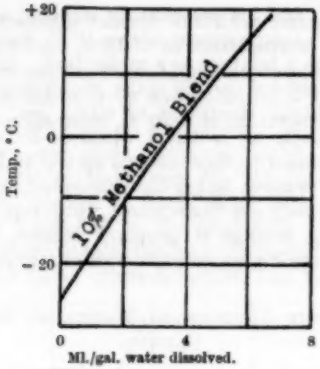

FIG. 23.

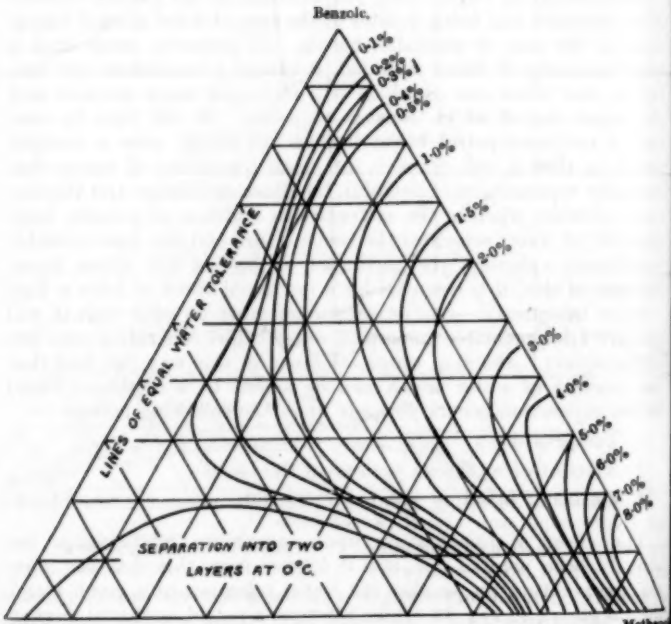

FIG. 24.

WATER TOLERANCES OF PETROL-BENZOLE-METHANOL MIXTURES AT 0°C.

used during this time with the utmost satisfaction. This curve shows that at a temperature of +15° C. no less than 6 ml. of water is dissolved per gallon of mixture before any separation occurs, whereas if 2 ml. of water were added and the fuel then subjected to a temperature of −10° C. separation would just occur. Referring to the effect of excess blending agent upon water tolerances, it follows that the greater this excess the greater the water tolerance. This is shown in Fig. 24, and it will be noticed that blends rich in benzole and methanol will dissolve as much as 8 per cent. of water at 0° C. without giving separation—this is equivalent to 360 ml. of water per gallon—or 0·64 pints per gallon.

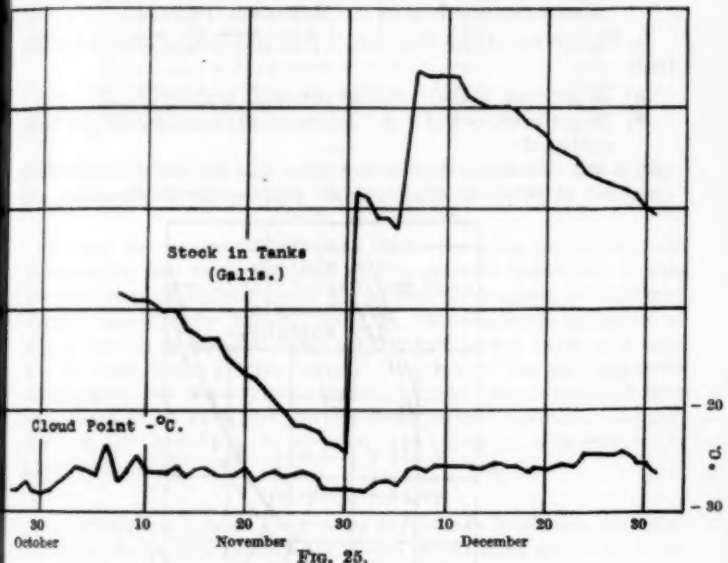

FIG. 25.

10 PER CENT. METHANOL BLEND IN GARAGE STORAGE TANK.

It has been stated in the technical Press that alcohol blends are hygroscopic and absorb water from the atmosphere. This is probably true, but experimental evidence shows that methanol is, in this respect, superior to ethyl alcohol and does not absorb water so readily. As already remarked, there has been on sale at the Billingham works of I.C.I., Ltd., for the past year, a petrol-methanol mixture stabilised by the addition of benzole. This blend has been mixed in the usual way at the refinery, transported to the

garage in a tank wagon, and there transferred to the underground tank connected to one of the garage pumps, from whence it is pumped in the usual way to customers' tanks. This methanol blend is stable at all temperatures down to about −28° C., and has a water tolerance of 3·5 ml./gal. water at 0° C. The blend has now been on sale for a year, and during the whole of this time not a single case of separation has been reported. The blend is perfectly stable, even in the coldest weather, and does not absorb water. The results of daily cloud point determinations on the blend, as taken from the garage pump, which show no water is absorbed, are presented in Fig. 25.

Distillation Curves of Methanol Blends.

In Fig. 26 are shown standard I.P.T. distillation curves for two fuels :—

(*a*) 70 per cent. petrol "A," 30 per cent. benzole ;
(*b*) 70 per cent. petrol "A," 20 per cent. benzole, 10 per cent. methanol ;

and it will be noticed that, in the latter case the per cent. distillate obtained at 60° C. is much greater than would be expected, and

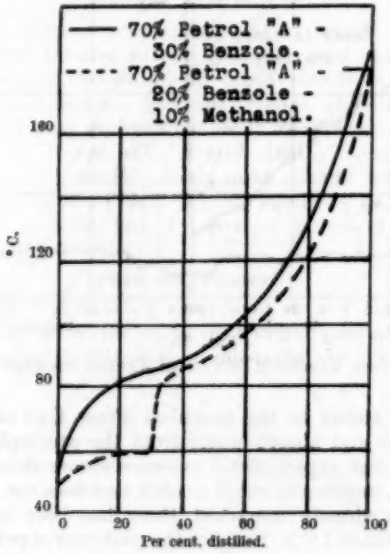

Fig. 26.

Effect of Methanol on Volatility Characteristics.

and that the curve has an unusual shape. This is due to the fact that methanol forms with benzole and with some other hydrocarbons constant boiling-point mixtures of minimum boiling point, as shown in Table V. This accounts for a high vapour pressure and a very good behaviour as far as engine starting is concerned.

TABLE V.

Constant Boiling Mixtures of Methanol with Hydrocarbons.

	Constant boiling point mixture.	
	B.P.° C.	% Wht. Methanol in mixture.
Isopentane B.P. 28° C.	24·5	4·0
Trimethylethylene B.P. 37·2° C. ..	31·75	7·0
Diallyl B.P. 60·2° C.	47·05	22·5
n-Hexane B.P. 68·95° C.	50·0	26·4
Benzene B.P. 80·2° C.	58·34	39·55
Cyclohexane B.P. 80·75° C. ..	54·2	37·2
Cyclohexene B.P. 82·75° C. ..	55·9	40·0
n-Heptane B.P. 98·45° C.	60·5	62·0
Methyl cyclohexane B.P. 101·8° C...	60·0	70·0
1·3 Cyclo hexadiene B.P. 80·8° C...	56·38	38·8

GENERAL NOTES ON THE BEHAVIOUR OF THE 10 PER CENT. METHANOL BLEND SOLD AT BILLINGHAM IN AUTOMOBILE ENGINES.

During the course of the past twelve months much valuable information has been obtained on the general behaviour of this 10 per cent. methanol blend in automobile engines of different types. As already shown, the fuel consumptions in terms of m.p.g. are no worse than those obtained on petrol alone, and they are in most cases a little better. The reason for this apparent discrepancy has already been given. Motor-cycle riders find that this blend is an excellent fuel for their high-compression engines, because all knocking is avoided and because acceleration is improved.

ACKNOWLEDGMENT.

In conclusion I wish to express my thanks to Messrs. Imperial Chemical Industries Limited, in whose laboratories the above work was carried out, for permission to publish this paper.

REVIEWS.

CHEMISTRY AND TECHNOLOGY OF CRACKING. By A. N. Sachanen, D.Sc., and M. D. Tilicheyev. Translated by A. A. Boehtlingk, D. F. Brown and K. T. Steik. New York, The Chemical Catalog Company, Inc., 1932. Pp. 389. $8.00.

Cracking processes of one kind and another have now been important economic features of the Petroleum Industry for over a decade. The genesis of these processes was doubtless largely empirical, but their full development has only been made possible by the sound application of basic principles of chemical engineering. With such extensive opportunities available and with well-trained and well-informed investigators interested in the subject, it is, therefore, surprising that so little has been recorded on the scientific and technological aspects of the subject. This may have been due to proprietorial interests, but one can only regret any cause withholding the dissemination of the results of fundamental and technical research on the big subject of hydrocarbon pyrolysis.

The book at present under review helps to fill in this gap. It is not a treatise. It presents in detail, and with the authors' thoughtful interpretation of the results, an account of several years' experimentation at the Petroleum Research Institute of the Grozneft, Grozny. It possesses, in full, the value which must always be attached to description of systematic trial, careful observation and reasonable deduction. The extent of ground covered is stupendous; the value of the conclusions drawn considerable. Yet during a study of the work one cannot but feel that much of the subject matter might better have appeared in the technical journals and the book itself have been written by one of the several well-known American men of science directly connected with the practice of cracking. In other words, "Chemistry and Technology of Cracking" has limitations. These are largely due to the conditions under which the underlying experiments were carried out, and they are amplified by the obvious dissociation of the authors from those countries, and particularly the U.S.A., where cracking had already become a deeply studied and well-practised art at the time Sachanen and Tilicheyev's experiments were instituted.

One must look somewhat askance at broad conclusions drawn from tests carried out in small autoclaves and supported, in defence of anticipated criticism regarding the conditions of heat transference, by the statement that "by measuring the temperature of the liquid under reaction we determine as accurately as possible the temperature of the 'contact surface' of the autoclave."

It is a pity too that in a book of this wide scope the translators could not have avoided the irritation caused by retention of terminology and standards unlikely to be understood by the British or American reader. Such criticism has partly been anticipated in the "Introduction," but does not dispose of what is a really adverse feature. A small matter, but also irritating, is the perpetuation of the word "pyrogenesis" as a synonym for cracking and, much worse, the frequent use of the term "pyrogenetic decomposition."

One half of the text is devoted to the chemistry and other fundamental features of cracking and to a description, in association therewith, of the cracking of various Russian crude oils and crude oil products. The remainder of the book is divided between an account of the properties and treatment of cracked products—gasoline, kerosine, residues, coke and gases—and short descriptions of nearly twenty of the principal cracking systems. It concludes

with a chapter on Hydrogenation which is chiefly concerned with the authors' own experimental work on the subject and is well worthy of close study.

The portions of the book given over to Sachanen and Tilicheyev's own work are very illuminating. With the limitations mentioned above they will serve as one of the standards of reference regarding behaviour of hydrocarbons under varying conditions of heat treatment. Much of the material has and will have direct value on cracking practice, and still more is of use in clarifying and systematising thoughts on such matters as re-cracking and the progressive relationship between liquid and vapour-phase cracking.

The authors may be forgiven for giving undue prominence to their known theories of carbon formation, but it is disconcerting to find a scientific discussion on hydrocarbon pyrolysis from this point of view without any mention of the work of Bone and Coward, and with the only reference to Berthelot the fact that he obtained diphenyl by passing benzene through a red-hot tube. Nevertheless, Sachanen and Tilicheyev give a complete and reasonable hypothesis of the general course of the changes involved in cracking oils of different types. In this as in other sections of their book they spare no pains in trying to bring all their facts into line.

It is not possible within the ordinary limits of a review to discuss the book in the detail it deserves and one would wish. There are excellent sections on the thermodynamics of cracking, on the analysis of cracked products, and on refining and use. To all interested in any respect of cracking the book can be commended as a distinct contribution to the literature of the subject.

S. J. M. AULD.

ORIGIN AND ENVIRONMENT OF SOURCE SEDIMENTS OF PETROLEUM. Parker D. Trask, assisted by Harald E. Hammar and C. C. Wu. Gulf Publishing Co., Houston, Texas, 1932. Pp. xv.+323. $6.00.

This important work embodies the results of investigations carried out by the authors over a period of five years under the auspices of the American Petroleum Institute and the Central Petroleum Committee of the National Research Council and made possible by the generosity of Mr. John D. Rockefeller.

The materials upon which the author and his assistants have worked consisted mostly of "coastal sediments and deposits from epicontinental seas and continental slopes" gathered together from many parts of the five oceans. Some of these collections were made by the author himself, but use was made also of samples in the possession of the U.S. Coast and Geodetic Survey as well as of Sir John Murray's historical collection by courtesy of the British Museum of Natural History.

The investigations, chemical and mechanical undertaken by the author are so varied in character and the descriptions so detailed and mathematical that it is impossible to do justice to them in the course of a brief review of the work. Twenty-five years ago the reviewer, in an early paper, prophesied that Geology would eventually become a mathematical science. The prophecy seemed a rash one at the time, but there is no doubt to-day of the increasing tendency in this direction. It is well illustrated in this book.

Some of the conclusions reached as the result of these investigations are of great importance to petroleum geologists, more especially those in connection with sedimentation. The effects of submarine relief on fineness and texture are particularly worthy of attention.

While the book is a noteworthy contribution to our knowledge of the subjects dealt with it is by no means the last word on them. The author has reached no definite conclusions as to what sediments constitute the mother rocks of petroleum, though it would almost appear that petroleum may be formed in almost any kind of sedimentary deposit, and that the concentration of oil into "pools" which may be profitably exploited may be due to conditions which lie outside the scope of these researches. A very important conclusion arrived at by the author and long suspected to be true by many geologists is that the question of plant or animal origin of petroleum is of no particular importance. The organic matter present in the source rocks may arise from either or both.

It is probably true that no other conclusions could have been reached from these investigations than those arrived at by the author, but it appears to the reviewer that a weak point may exist. Where the samples were not personally collected, but were obtained from other sources it is certain that many came from localities and locations which would not have been chosen by the author himself and would, therefore, not be the best fitted for the object in view. Moreover, the number of samples examined is few relative to the vast area covered so that it is possible that further work may cause certain conclusions to be modified. For example, the author states that no petroleum was found in samples of recent sediments examined, though such occurrences of petroleum have been recorded by other workers.

To carry this particular line or research much further it would probably be necessary to have collaborators in many different parts of the world carrying out investigations locally under the direction, say, of Mr. Trask.

The figuring on some of the maps is, in some cases, poor and confusing. A general bibliography dealing with the subject would be a great boon for there are many papers other than those referred to in the text. This is a book which no petroleum geologist can afford to overlook. It is a difficult book to read, but considering the importance of many of the subjects dealt with and the light which is thrown on many field problems it is well worth the trouble.

A. WADE.

Knock-Rating of Motor Fuels.

The Standardization Committee of the Institution of Petroleum Technologists have decided that the I.P.T. Standard Method of Test for the Determination of the Knock-Rating of Motor Fuels shall be the C.F.R. Motor Method adopted as a Tentative Standard by the American Society for Testing Materials. This Method is to be effective in Great Britain as from May 1st, 1933.